Fatigue and pacing in rugby league players

Richard Johnston

Australian Catholic University

This thesis is submitted in accordance with the requirements of The Graduate Research Office, Australian Catholic University for the degree of Doctor of Philosophy by Richard Johnston.

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Declaration

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No parts of this thesis have been submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

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Published Works by the Author Incorporated into the Thesis

The studies outlined below were conducted during this PhD and make up the presented thesis; each paper has been published following peer review.

1. Johnston RD, Gabbett TJ, and Jenkins DG. Applied sport science of rugby league. *Sports Med*, 2014, 44: 1087-1100. Impact Factor = 5.32; Citations = 7

Statement of Authorship

Richard Johnston, Tim Gabbett, and David Jenkins were involved in 70, 20, and 10% of writing the above paper.

Rich Johnston

Tim Gabbett

David Jenkins

2. Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on pacing strategies during game-based activities. *Int J Sports Physiol Perform*, 2014, 9: 811-6. Impact Factor = 2.68; Citations = 9

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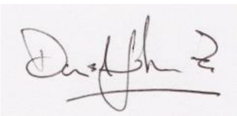
Rich Johnston

Tim Gabbett

Anthony Seibold



David Jenkins

3. Johnston RD, Gabbett TJ, Walker S, Walker B, and Jenkins DG. Are three contact efforts really reflective of a repeated high-intensity effort bout? *J Strength Cond Res*, 2015, 29: 816-821. Impact Factor = 1.85; Citations = 0

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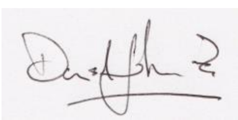
Richard Johnston was involved in 30% of the study development, 80% of the data analysis, and 70% of writing the above paper. Tim Gabbett was involved in 30% of the study development, 60% of the data collection, 20% of the data analysis, and 20% of writing the above paper. Shane Walker was involved in 10% of the study development and 20% of the data collection. Ben Walker was involved in 10% of the study development and 20% of the data collection. David Jenkins was involved in 20% of the study development and 10% of writing the above paper.

Rich Johnston

Tim Gabbett

Shane Walker

Ben Walker



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4. Johnston RD, Gabbett TJ, and Jenkins DG. Influence of the number of contact efforts on running performance during game-based activities. *Int J Sports Physiol Perform*, 2015, 10: 740-745. Impact Factor = 2.68; Citations = 1

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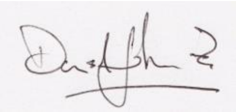
Rich Johnston

Tim Gabbett



David Jenkins

5. Johnston RD, Gabbett TJ, and Jenkins DG. Pacing strategies adopted during an intensified team sport competition depend on playing standard and physical fitness. *Int J Sports Physiol Perform,* 2015, March 10, in press. Impact Factor = 2.68; Citations = 1

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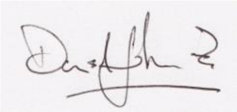
Rich Johnston

Tim Gabbett



David Jenkins

6. Johnston RD, Gabbett TJ, and Jenkins DG. Influence of an intensified competition on fatigue and match performance in junior rugby league players. *J Sci Med Sport*, 2013, 16: 460-5. Impact Factor = 3.07; Citations = 18

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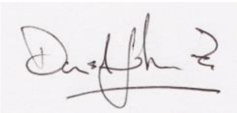
   Richard Johnston was involved in 40% of the study development, 60% of the data collection, 90% of the data analysis, and 70% of writing the above paper. Tim Gabbett was involved in 40% of the study development, 40% of the data collection, 10% of the data analysis, and 20% of writing the above paper. David Jenkins was involved in 20% of the study development and 10% of writing the above paper.

Rich Johnston

Tim Gabbett



David Jenkins

7. Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games. *J Sci Med Sport*, 2014, 17: 535-40. Impact Factor = 3.07; Citations = 13

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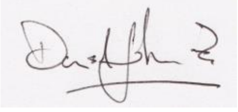
Rich Johnston

Tim Gabbett

Anthony Seibold



David Jenkins

8. Johnston RD, Gabbett TJ, Jenkins DG, and Hulin BT. Influence of physical qualities on post-match fatigue in rugby league players. *J Sci Med Sport*, 2015, 18: 209-213. Impact Factor = 3.07; Citations = 12

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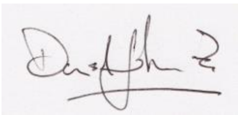
Rich Johnston

Tim Gabbett



David Jenkins

Billy Hulin

9. Johnston RD, Gabbett TJ, and Jenkins DG. Influence of playing standard and physical fitness on activity profiles and post-match fatigue during intensified rugby league competition. *Sports Med Open*, 2015, March 22. Impact Factor = N/A; Citations = 1

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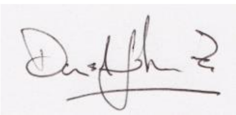
Rich Johnston

Tim Gabbett



David Jenkins

10. Johnston RD, Gabbett TJ, Jenkins DG, and Speranza, MJ. The effect of different repeated high-intensity effort bouts on subsequent running, skill performance and neuromuscular function. *Int J Sports Physiol Perform, in press,* 2015.

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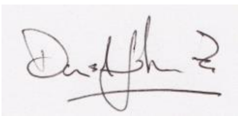
Richard Johnston was involved in 35% of the study development, 70% of the data collection, 90% of the data analysis, and 70% of writing the above paper. Tim Gabbett was involved in 35% of the study development, 10% of the data analysis, and 20% of writing the above paper. David Jenkins was involved in 20% of the study development and 10% of writing the above paper. Michael Speranza was involved in 10% of the study development and 30% of the data collection.

Rich Johnston

Tim Gabbett



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Abstract

Players from a number of team sports such as soccer, Australian rules football, and rugby league adopt pacing strategies during match-play in order to successfully complete match tasks without causing the failure of any single physiological system. Whilst these pacing strategies are influenced by numerous factors, it is currently unclear how physical qualities, physical contact, and time between matches influence pacing strategies. Given the frequency of physical collisions during match-play and the close link between physical qualities and success in rugby league, it is important to determine the impact they have on running intensities and pacing strategies employed by players. In addition, when players have little time to recover between matches, such as during a tournament, they may alter their pacing strategies to manage the fatigue that could occur across the period of congested fixtures.

The demanding nature of competition results in players experiencing perceptual and physical fatigue that persists for a number of days following rugby league competition. Although the time course of the fatigue responses are well understood, little is known as to how fatigue impacts match activities and whether the fatigue response can be modified. Previous research has shown positive correlations between physical contact and markers of muscle damage; however as collisions make up a large proportion of the game, further work is required to determine the true cause and effect of physical contact. Although post-match fatigue is inevitable, various recovery interventions (e.g. ice baths, active recovery, compression garments) are often employed in an attempt to accelerate the recovery process. Despite this, the efficacy of many of these strategies has often been questioned. Given that well-developed physical qualities are associated with reduced transient fatigue and can be easily improved via training, it would appear important to determine the impact various physical qualities have on the fatigue response to match-play.

With this in mind, the overall aims of this thesis were to determine the impact of physical contact, physical qualities, and periods of congested fixtures on pacing strategies and markers of fatigue and muscle damage in rugby league players. The thesis comprised 9 individual studies divided into two separate, yet interlinking themes. The first theme focused on player workloads, pacing strategies, and match intensities; the second on the fatigue response to these physical demands. Studies 1-3 investigated the influence of contact on subsequent

running performance as well as the relationship with aerobic fitness and strength qualities. We found that performing contact within small-sided games leads to greater reductions in running performance as players employ a pacing strategy that prioritises the maintenance of contact efforts over running efforts. Increasing the contact demands leads to further reductions in running intensities. Subsequent studies also confirmed these findings, highlighting that there were greater reductions in running intensities during small-sided games following contact dominant repeated-effort activity as opposed to following running dominant activity. In Theme 2, we investigated the impact of physical contact on fatigue and muscle damage. The addition of physical contact to small-sided games resulted in upper-body fatigue as well as larger increases in blood creatine kinase compared to following non-contact small-sided games. In addition, we also found that increased running loads resulted in greater lower-body fatigue, whereas increased contact loads lead to increased upper-body fatigue. These data indicate that performing physical contact leads to larger increases in muscle damage and upper-body fatigue compared to exercise involving no contact. Furthermore, the location of fatigue sustained (e.g. upper- or lower-body) is sensitive to the activity performed. In Theme 2 we also investigated the fatigue response during an intensified competition and explored the relationship between fatigue and match activities. Increased creatine kinase, a marker of muscle damage, was related to reductions in match activities. Exploring the relationships between physical fitness, match activities and post-match fatigue response following both single matches and during a tournament provided some interesting results. We found players with well-developed physical qualities had higher work-rates, which could be maintained over a number of games, as well as less post-match fatigue. This suggests that physical qualities offer a protective effect against post-match fatigue.

Summary

In summary, the findings of the conducted experiments demonstrate that:

1. Physical contact is physically demanding leading to both reductions in running intensities during small-sided games and increases in markers of upper-body fatigue and skeletal muscle damage.
2. High-intensity running does not adequately prepare players for the intense contact demands of competition.
3. Players with well-developed physical qualities set higher pacing strategies, which they can maintain for longer than players with poorly developed physical qualities.
4. Markers of fatigue accumulate over intensified competition; these symptoms are greater in the forwards compared to backs. Increased fatigue and muscle damage contribute to reductions in high-intensity match activities such as repeated high-intensity effort bouts.
5. Aerobic fitness and lower-body muscular strength have a protective effect against post-match fatigue and muscle damage following both single games and intensified competition. In addition, players with well-developed physical qualities have greater absolute and relative workloads than their less fit counterparts.

Collectively these data highlight that well-developed physical qualities lead to greater relative and absolute workloads during match-play and game based training as well as lower levels of fatigue and muscle damage. Despite the high physiological and functional cost of performing physical contact, players need to be exposed to the most intense contact and running demands of competition during training. This will allow appropriate physical qualities to be developed that lead to increased player work-rates as well as reductions in post-match fatigue.

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List of Abbreviations

All abbreviations will be highlighted in full upon first use in each chapter or individual study, before appearing in abbreviated form for the remainder of the chapter or study. A list of all abbreviations used in the thesis appears below.

30-15 IFT	30-15 Intermittent Fitness Test
∑ 7	Sum of 7
BT	Bench throw
CI	Confidence interval
CK	Creatine kinase
cm	Centimetre
CMJ	Countermovement jump
CR-10	Category ratio scale 10
CV	Coefficient of variation
ES	Effect size
ESL	European Super League
GPS	Global positioning system
HSR	High-speed running
ICC	Intraclass correlation coefficient
kg	Kilogram
LSA	Low-speed activity
min	Minute
$ml·kg^{-1}·min^{-1}$	Millilitres per kilogram per minute
mm	Millimetres
MSR	Moderate-speed running
$m·min^{-1}$	Metres per minute
$m·s^{-1}$	Metres per second (velocity)
$m·s^{-2}$	Metres per second (acceleration)
no.	Number
no./min	Number per minute
NRL	National Rugby League
NYC	National Youth Competition
PP	Plyometric push-up
RHIE	Repeated high-intensity effort

RM	Repetition maximum
RPE	Rating of perceived exertion
s	Seconds
SD	Standard deviation
SE	Standard error
SEE	Standard error of the estimate
SJ	Squat jump
SSG	Small-sided game
TE	Typical error of measurement
VJ	Vertical jump
$\dot{V}O_2$ max	Maximal oxygen consumption
W	Watts
Yo-Yo IRT	Yo-Yo Intermittent Recovery Test

Navigation of the Thesis

The work presented in this thesis is based upon previous literature discussed in the introduction. The thesis itself is comprised of two distinct, yet interrelating themes. The first theme investigates how physical contact and fitness impact on pacing strategies employed by players during match-play and game based training. Each of the studies in this theme are linked to each other as we initially investigate the impact of single and then multiple physical contact efforts on pacing strategies employed by players during small-sided games. In addition, the influence of high-intensity running ability, as well as upper- and lower-body strength on activities performed during small-sided games was investigated. The final study in this theme built upon the third study by investigating the influence of physical fitness on the pacing strategies employed by players during an intensified competition and whether these pacing strategies were also influenced by playing standard.

The second theme in this thesis centres on fatigue responses following rugby league competition and small-sided games. The first study in this series investigates the fatigue responses to an intensified rugby league competition and how fatigue is influenced by playing position and the relationship with match activities. This initial study found a relationship between increases in markers of muscle damage and the number of contacts players performed over the competition. As such, in our second study, we subsequently aimed to determine the true impact of physical contact on markers of fatigue and muscle damage. The third and fourth study aimed to determine the influence of physical fitness and playing standard on the fatigue response to both single fixtures and intensified competition.

Based on the results from previous studies in this thesis, the final study (study 9) investigated both pacing and fatigue during small-sided games following repeated effort exercise involving varying amounts of contact and running. In particular, given that we previously demonstrated greater reductions in small-sided game running intensities as the number of contacts per bout increased, we assessed whether this trend was different when the high-intensity bouts were more match-specific and included a combination of contact and running efforts. Moreover, given that we highlighted that there were increases in upper-body fatigue with contact and increases in lower-body fatigue with running loads, we explored these results further by quantifying the upper- and lower-body fatigue response to running dominant and contact dominant high-intensity activity.

Whilst there are two separate themes of studies within this thesis, there is a global theme of the influence of fitness, physical contact, and congested fixture periods on (1) activity profiles and pacing strategies, and (2) the fatigue response to competition demands and the causes and consequences of this fatigue. Moreover, a number of the studies within this thesis draw upon both of the described themes. The links between papers within this thesis are illustrated in Figure 1.The rationale for each of these studies is explained in the following section.

Chapter 1

General Introduction

1.1 Overview of Rugby League

Rugby league is an intermittent team sport played internationally by junior and senior players at professional, semi-professional and amateur levels. Over the course of a game, players are required to perform bouts of high-intensity activity (e.g. high-speed running, sprinting and physical collisions) separated by short recovery bouts of lower intensity activities (e.g. standing, walking, jogging) [1-8]. While rugby league requires players to perform numerous bouts of high-speed running, unlike other team sports players are required to compete in frequent physically demanding collisions, and wrestles over the course of a game [9-11]. These physical contests between players are particularly fatiguing, and make the demands of rugby league unique.

1.2 Theme 1 – Factors influencing pacing strategies in rugby league players

Research from self-paced endurance sports has highlighted a number of different pacing strategies are employed by athletes in order to deliver optimal performances without causing physiological failure [12, 13]. In addition, pacing strategies are also adopted during pre-determined repeated-sprint activity [14]. However, in team sports, the stochastic nature of match-play and ever changing contextual factors make a closely controlled pacing strategy more difficult to implement. Recent research from sports such as rugby league [15, 16], Australian rules football [17, 18] and soccer [19], has reported the use of pacing strategies in team sports. Much of this evidence suggests that as the game progresses, players employ a pacing strategy whereby they reduce low-speed activity in order to maintain high-intensity actions [17, 18, 20]. It is clear that numerous factors influence pacing strategies during self-paced events, including changes in core temperature [18, 21], knowledge of exercise end-point [14, 22], bout duration [15, 16, 22], match outcome [15] and substrate availability [12]. Despite this, there is currently limited evidence documenting the influence of match activities, periods of congested fixtures, playing standard and/or physical fitness on the pacing strategies employed by players.

Interchange players in rugby league pace at a higher intensity than whole-match players due to shorter periods of match-play [16]; on the other hand, whole-game players set an intensity that allows them to complete the game in a reasonable physical state [15, 16]. In addition, players from winning sides appear to adopt similar pacing strategies to players from losing sides, except they maintain a higher intensity of match-play [15]. This trend is apparent for both whole-match and interchange players. However, the influence of physical qualities on these pacing strategies is unclear [23, 24]. It is also unclear as to the effect of other factors, such as physical contact, fitness and time between fixtures, on pacing strategies employed during competition. There is a high frequency of physical contact during competition, with players often being required to perform as many as 1.9 ± 0.7 collisions per minute of match-play [25] as well as maintaining running intensities as high as 125.1 ± 16.1 m/min when the ball is in play [26]. These demands are particularly challenging with previous research indicating that physical contact increases the physiological responses to repeated-sprint activity as well as causing performance reductions [9] and elevations in fatigue [27]. Despite this, it remains unclear as to the effect of physical contact on running intensities and pacing strategies during small-sided games. Physical fitness is closely linked to success in rugby league with numerous qualities being related to match activity profiles [24, 28]; although to date, it is unclear as to whether pacing strategies differ based on physical qualities. Players in numerous team sports regularly compete in tournaments where they are required to play a number of games within a short period of time [29]. During such periods, pacing strategies may differ to those seen during regular competition; players may adjust match activities in an attempt to minimise post-match fatigue that are linked to reductions in physical and technical match activities [30].

1.3 Theme 2 – Residual fatigue in rugby league players: causes and consequences

Given the demanding nature of match-play, players experience immediate and delayed feelings of perceptual and physical fatigue that persist for a number of days following rugby league competition. Previously, studies have reported impairments in whole body neuromuscular function [27, 30-34], increases in markers of skeletal muscle damage [27, 30, 34-36], and reductions in perceived wellbeing [27, 30, 32] following rugby league matches, typically persisting for 24-48 hours following competition. However, elevations in blood creatine kinase (CK), an indirect marker of muscle damage, may last up to 120 hours [34, 35]. During the competitive season, games are generally separated by 5-10 days, providing players with sufficient time to recover, given appropriate training and recovery interventions are employed. Despite this, there are periods during the season, when players are required to play multiple games within a week [30]. Previous research has shown that during intensified rugby league [30], basketball [29], and soccer competition [37], high-intensity match activities and technical performance become compromised in the latter stages of the tournament as fatigue accumulates. Recent research from Australian rules football has suggested that increased neuromuscular fatigue results in an increased proportion of match activity spent at lower speeds and fewer accelerations as well as limiting the positive influence well-developed physical qualities have on match performance [38, 39]. In addition, elevated blood CK prior to competition is also linked to reductions in match performance [40]. In spite of this, there is no research in rugby league that demonstrates that increases in markers of fatigue impact on either technical or physical match performance. Given that the demands of rugby league are vastly different to Australian rules football, with greater contact demands and lower running loads [41], it is likely that the fatigue markers and their relationship to performance will also differ. As such, it is important to investigate the relationships between markers of fatigue and physical and technical match performance in rugby league players.

Certain activities performed during competition appear to increase post-match fatigue. Increases in playing time and match speed results in greater reductions in post-match muscle function [31]. In addition, physical contact comprises a large proportion of match-play, with players being involved in frequent collisions in both attack and defence [5, 25]. Twist et al.,

[27] reported that the total number of contact efforts performed during competition was correlated with post-game increases in CK and reductions in jump height. Furthermore, physical contact caused greater reductions in repeated-sprint performance when performed intermittently with sprints as opposed to repeated sprints alone [9]. This suggests that performing contact efforts results in increased muscle damage and fatigue. Despite this, the study by Twist et al. [27] does not show cause and effect, and the repeated-effort drill used by Johnston and Gabbett did not closely replicate the demands of rugby league match-play. Given the frequency of physical collisions [25], it is important to quantify the physiological cost of these contact efforts so coaches can appropriately prescribe training with these demands in mind.

Given that fatigue is an inevitable response following competition, during a prolonged competitive season that can last for 7-8 months of the year with regular weekly competitions, it would appear important to minimise the disruption post-match fatigue has on the training process. Whilst various interventions are often employed to facilitate recovery following match-play, their efficacy is often questioned [42, 43]. Currently, it is unclear whether any intrinsic qualities influence the fatigue response observed following competition. Findings from Australian rules football demonstrated that across a season, players with better 6 min run performance showed smaller disturbances in blood CK prior to competition [40]. Also, well-developed physical qualities reduce transient fatigue and promote recovery following intense physical exertion [44]. In particular, greater aerobic fitness results in smaller decrements in repeated-sprint performance [45, 46]. As such, fitter athletes may experience smaller metabolic disturbances following high-intensity activity, resulting in less acute fatigue [44]. Whilst speculative, this could translate to reduced residual fatigue, and accelerated recovery following competition. As well as aerobic qualities, muscular strength may also influence post-match fatigue. Although collisions play a major role in the muscle damage and fatigue response [27], high-speed movements also induce symptoms of fatigue [27, 30, 47]. Therefore, players who possess greater muscular strength and eccentric strength in particular, may be more suited to dealing with the forces associated with these movements. Greater strength appears to augment the stretch-shortening cycle, potentially placing less stress on the contractile components of the muscle [48, 49]. Indeed, Byrne et al. [50] suggested that enhancing the stretch-shortening cycle capabilities of the muscle may moderate the effects of muscle damage. Therefore, greater muscular strength may limit neuromuscular fatigue and muscle damage following match-play. In addition, to the potential protective effects of well-developed physical qualities on post-match fatigue, they are also linked to increased work-rates during competition [24, 28]. As such, it is an attractive notion that enhancing physical qualities, which can be easily achieved via training, may increase performance, yet reduce post-match fatigue.

1.4 Aims of the Current Research

The overall aims of this thesis were to determine the impact of physical contact on transient fatigue, residual fatigue, muscle damage, and pacing strategies during training and competition. Furthermore, we sought to identify the impact of residual fatigue and muscle damage on match activities and whether fatigue is modified by physical qualities. Results from this research will provide coaching and support staff with a greater understanding of factors that influence fatigue and how the fatigue response to competition can be modified.

1.4.1 Theme 1 Aims

Based on the gaps in the literature highlighted above, it appears important to determine the influence of physical fitness and contact on pacing strategies during small-sided games and match-play. Such information will potentially provide coaches with information to prepare their own players for the most extreme demands of competition as well as tactics to target opposition players. In order to address these questions, we developed a series of studies that can be seen in Figure 1.1 under the heading *"Theme 1 – Factors influencing pacing strategies in rugby league players"*. The first study assessed the influence of single, and the second study, multiple contact efforts on pacing strategies during small-sided games, and whether 3 contacts were actually reflective of a repeated high-intensity effort (RHIE) bout. The third study sought to determine the relationship between physical qualities and player movements during different small-sided games where the volume of contacts was increased across each game. Study four examined pacing strategies employed during intensified competition and whether this was linked to playing standard and physical fitness. Study 5, which drew upon the pacing theme and the fatigue theme, examined the impact of different RHIE bouts (i.e. contact or running dominant bouts) on running intensities during small-sided games. It was hypothesised that (1) increasing the contact demands of training games would result in greater reductions in running intensity (2) players would adopt different pacing strategies when they were required to perform physical contact (3) high-intensity running ability would have a reduced influence on running intensities as the contact demands were increased and (4) well-developed aerobic fitness would result in a higher pacing strategy across an intensified competition. Study 4 within this theme is also linked to Theme II within this thesis as it investigated the impact of physical qualities on pacing strategies employed during intensified competition.

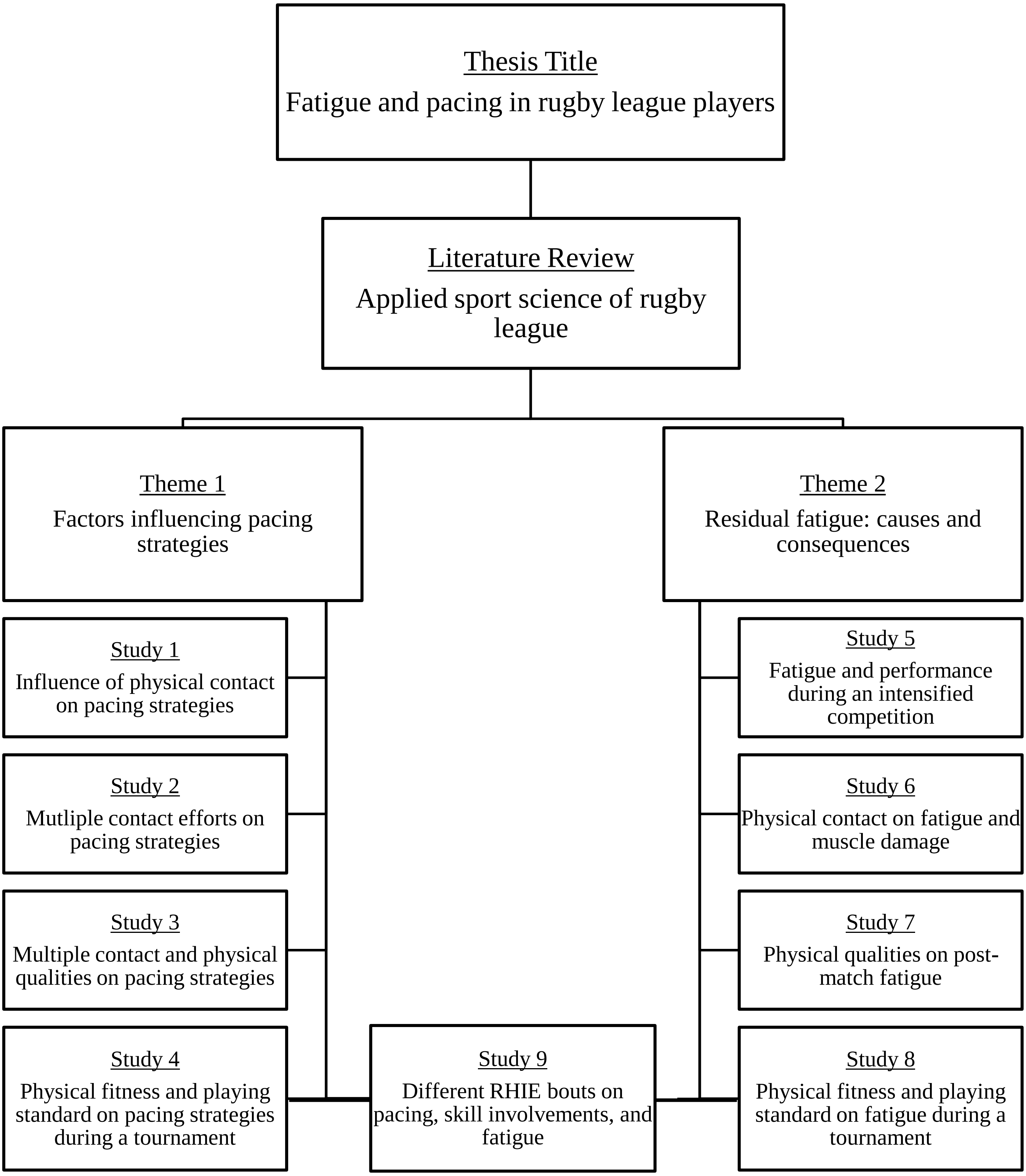

Figure 1.1 Schematic overview of the studies that comprised each theme of the thesis. RHIE = repeated-high intensity effort.

1.4.2 Theme 2 Aims

Based on the previous literature, there were a number of aims within this theme of the thesis. The first aim was to determine the fatigue response to intensified competition and explore any relationships between fatigue and match activities. This would allow us to determine the utility of various fatigue markers for assessing a player's readiness to train or deliver successful match performances. The studies that addressed these aims were studies 1 and 4 from Theme 2, highlighted in Figure 1.1 under *"Theme 2 – Residual fatigue in rugby league players: causes and consequences"*. Both of these studies tracked match activities and fatigue over intensified junior rugby league tournaments to observe the interaction between fatigue and match activities. It was hypothesised that (1) markers of fatigue and muscle damage would increase and performance would be reduced as the intensified competition progressed; and (2) markers of fatigue and muscle damage would be related to these reductions in match performance. Given the high frequency of physical contact in rugby league, the second aim was to determine the influence of physical contacts on CK, fatigue and running performance during game–based activities. Due to the large involvement of the upper body during collisions in match-play [11], it was important to quantify the fatigue induced to the upper-body so that the fatigue response was not underestimated by just examining lower-body fatigue. It was hypothesised that physical contact would result in increased upper-body neuromuscular fatigue and markers of skeletal muscle damage. The study that primarily addresses this question is "Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games" in Theme 2 (Figure 1.1). Whilst this study examines the residual fatigue response to contact, there is a link with studies 1, 2, and 3 from Theme I, which investigated the influence of contact on transient fatigue during small-sided games. The third aim of this theme was to determine the impact of physical qualities on the fatigue response observed following competition. It was hypothesised that enhanced physical qualities would lead to increased playing intensities, yet reduced fatigue following single games as well as intensified competition. There are two studies within Theme II of this thesis that attempted to address this question. The first is entitled *"Influence of physical qualities on post-match fatigue in rugby league players"*; a subsequent study was then developed to assess the influence of physical qualities on fatigue during an intensified competition, entitled *"Influence of playing standard and physical fitness on activity profiles* *and post-match fatigue during intensified rugby league competition"*. The link between these studies and the thesis as a whole can be seen in Figure 1.1.

Chapter 2

Literature Review: Applied sport science of rugby league

This literature review has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, and Jenkins DG. Applied sport science of rugby league. *Sports Med*, 2014, 44: 1087-1100.

Since the publication of this paper, there have been some additional papers of note that are included within this section of the thesis. As such, the literature review that appears within this thesis differs slightly from the one published within *Sports Medicine*.

2.1 Abstract

Rugby league is a team sport in which players engage in repeated high intensity exercise involving frequent collisions. Recent research, much of which involving global positioning system (GPS) technology, has provided coaches and sport scientists with a deeper understanding of match demands, particularly at the elite level. This has allowed for the development of training programs that prepare players for the most intense contact and running demands likely to be experienced in competition. At the elite level, rugby league players have well-developed aerobic and anaerobic endurance, muscular strength and power, reactive agility, and speed. Upper and lower-body strength and aerobic power are associated with a broad range of technical and sport-specific skills, in addition to a lower risk of injury. Significant muscle damage (as estimated from creatine kinase concentrations) and fatigue occurs as a result of match-play; while muscle function and perceptual fatigue generally return to baseline 48 hours following competition, increases in plasma concentrations of creatine kinase can last for up to 5 days post-match. Well-developed physical qualities may minimise post-match fatigue and facilitate recovery. Ultimately, the literature highlights that players require a broad range of physical and technical skills developed through specific training. This review evaluates the demands of the modern game, drawing on research that has used GPS technology. These findings highlight that preparing players based on the average demands of competition is likely to leave them underprepared for the most demanding passages of play. As such, coaches should incorporate drills that replicate the most intense repeated-high intensity demands of competition in order to prepare players for the worst-case scenario expected during match-play.

2.2 Rationale

Rugby league is an intermittent team sport played internationally by junior and senior players from elite to non-elite standards. During a match, players perform bouts of high-intensity activity (e.g. high-speed running and sprinting) separated by short bouts of lower intensity activities (e.g. standing, walking, and jogging) [1-8]. In addition to the numerous bouts of high-speed running, players also frequently engage in physically demanding collisions, and wrestling bouts [9-11]. For information on the origin and rules of rugby league, readers are referred to a previous review [51]. The sport science and physiology of rugby league have been reviewed only three times; in 1995 [52], 2005, [53] and 2008, [51]. Since 2008, there have been a number of advancements in sport science technology and global positioning system (GPS) microtechnology devices in particular. GPS has been used in the National Rugby League (NRL) since 2009 and in the European Super League (ESL) since 2010, providing more detailed information regarding the physical demands of the game. There has also been an exponential rise in applied rugby league research. In the 5 years since the last review (2008), a search of PubMed for the term "rugby league" returned 129 results, compared to the 48 results in the 5 years prior to 2008. Furthermore, various rule changes since 2008 are likely to have altered the demands of the game and therefore player preparation. The NRL and ESL reduced the number of interchanges permitted by each side from 12 to 10 in 2008 and 2012, respectively. In 2009, the NRL introduced 2 referees to officiate matches; ESL and international games are still officiated by a single referee [2]. Quantifying the demands of rugby league match-play is important in developing specific training drills to appropriately prepare players for the rigours of competition. Given the large body of literature that has been published since the last review, an update on the applied sport science literature relating to rugby league will provide practitioners and researchers alike with an overview of the game as it presently stands. Data referred to in the text are means ± standard deviation unless otherwise stated.

2.3 Physical Demands

2.3.1 Quantifying Demands

Much of the research described in the previous rugby league reviews [51-53] involved the manual coding of video footage, classifying activities into 'zones' based on subjective analysis of movements [3, 6, 7, 54]. While this approach is reliable [3, 7], coding is labour-intensive, which has limited these studies to small sample sizes. Recent developments in GPS technology have allowed the movement patterns to be assessed objectively and with greater ease, allowing large numbers of players to be monitored during competition. Published articles describing the competition demands of rugby league using GPS [2, 4, 5, 8, 15, 16, 26, 41, 55-65] have extended our understanding of the physical demands of the game. Despite these advances, there are some issues regarding the quantification of match demands. Firstly, the reliability and validity of GPS devices in measuring movements, particularly short, high-intensity activities has been questioned, but as the technology (and sampling frequency) has developed so too has the accuracy [66]. Secondly, different devices used across studies makes comparisons difficult, and may explain some of the disparities seen [67]. Finally, there is little consistency between researchers in the velocity zones used for low-speed (0-1.9, 1-3, 0-2.7, 0-3.3, and 0-5 m·s^{-1}), moderate-speed (1.9-3.9, 2.7-5, 3-5, and 3.3-5 m·s^{-1}), high-speed (3.9-5.8, 5-5.5, 5-6.1, and 5-7 m·s^{-1}), and very high-speed/sprinting activity (>5.5, >5.6, >5.8, >6.1, >7 m·s^{-1}) [4, 8, 56, 57, 59, 61]. More information on GPS technology can be found in these recent reviews [66, 68-70].

2.3.2 Total Distance

The physical demands of rugby league competition have been analysed in elite (professional) [2, 4, 5, 8, 55, 56, 58, 59, 61, 62, 65, 71], semi-elite (semi-professional) [15, 26, 61, 63, 65], non-elite (amateur) [30, 31], and junior players [58, 60, 61, 64] (Table 2.1). Over the course of a match, players typically cover 4,000-8,000 m depending on playing position and standard [2, 8, 30, 31, 56, 58, 59, 61]. The outside backs cover the greatest distances (~5,500-8,000 m) followed by the adjustables (~6,000-7,000 m), and hit-up forwards (~3,500-6,000 m) [2, 8, 56, 58, 59].

Differences in absolute distance are less clear when expressed relative to playing time (Table 2.1). There are small differences between positions, with some [8, 56, 58, 61, 62], but not all studies [2, 58, 61], suggesting that forwards cover the greatest relative distances. These conflicting findings could be related to the style of play of individual teams rather than a reflection of the game as a whole. Similar playing intensities can be largely attributed to the forwards spending less time on the field than other positions, typically playing 40-50 minutes [2, 8, 62]. Elite NRL and ESL players typically cover 90-100 m·min^{-1} [2, 5, 8, 58, 61, 62]. On average, semi-elite and junior elite players cover lower relative distances than elite players (88 m·min^{-1} vs. 95 m·min^{-1}) [15, 58, 61, 64, 72] (Table 2.1); the intensity of non-elite matches is lower once again (75-83 m·min^{-1}) [31, 30, 60]. This could be due to reduced physical [73, 74] and skill qualities [75] in non-elite players leading to lower work rates, more errors and stoppages during competition and reductions in match intensity.

Relative distance covered (or match intensity) appears important to the outcome of a match. In elite and semi-elite competition, greater relative distances are covered by winning sides [55, 15], suggesting that the ability to maintain high work rates is linked to match outcome. It is important to recognise that the average match intensity does not highlight the most demanding passages of match-play [25, 26, 63, 76, 77]. Preparing players based on these average intensities is likely to result in players being underprepared for competition [25, 76]. Indeed, when only assessing ball in play time rather than the whole game (including stoppages), the match intensity is significantly greater (125 ± 16.1 $m \cdot min^{-1}$ vs. 86.7 ± 9.8 $m \cdot min^{-1}$) [26]. In addition, relative distance covered varies depending on field position and phase of play. Relative distance is greatest when defending in the 70-100 m zone compared to 0-30 m zone (117.2 ± 29.1 $m \cdot min^{-1}$ vs. 100.4 ± 28.9 $m \cdot min^{-1}$; Effect size [ES] = 0.65) [25]. As such, coaches should be mindful of these increased demands when prescribing the intensities of conditioning drills. Collectively, these data highlight the importance of players maintaining high match intensity, as well as possessing the ability to increase intensity at critical periods of the match.

Table 2.1. Movement demands of rugby league competition across playing standards and positions.

Study	**Group**	**Playing time (min)**	**Distance (m)**	**Distance ($m \cdot min^{-1}$)**	**LSA (m)**	**HSR (m)**	**RHIE bouts (no.)**
Austin & Kelly [56]	NRL forwards	-	5964 ± 696	85 ± 4	4655 ± 568	432 ± 127	-
	NRL backs	-	7628 ± 744	86 ± 5	5844 ± 549	749 ± 205	-
Gabbett et al. [2]	NRL hit-up forwards	38.0 ± 10.8	3569 ± 1177	94 ± 10	3334 ± 1082	235 ± 122	8.0 ± 5.2
	NRL WR forwards	58.5 ± 16.7	5561 ± 1579	96 ± 13	5143 ± 1474	418 ±154	9.9 ± 6.4
	NRL adjustables	64.1 ±23.0	6411 ± 2468	101 ± 19	5974 ± 2299	436 ± 198	8.6 ± 7.7
	NRL outside backs	73.5 ± 14.9	6819 ± 1421	93 ± 13	6235 ± 1325	583 ± 139	8.5 ± 5.4
Gabbett [58]	NRL forwards	50.7 ± 13.1	5129 ± 1652	105 ± 21	4878 ± 1541	251 ± 157	11.9 ± 6.2
	NRL adjustables	74.9 ± 14.6	7834 ± 2207	99 ± 8	7513 ± 2138	320 ± 176	14.3 ± 5.4
	NRL backs	77.8 ± 10.1	7575 ± 850	94 ± 10	7123 ± 830	452 ± 113	14.5 ± 5.4
McLellan et al. [59]	NRL forwards	-	4982 ± 1185	-	4664 ± 1165	232 ± 60	-
	NRL backs	-	5573 ± 1128	-	4879 ± 1339	440 ± 101	-
McLellan & Lovell [61]	NRL forwards	-	8442 ± 812	98 ± 12	-	-	-
	NRL backs	-	8158 ± 673	101 ± 8	-	-	-
Twist et al. [62]	NRL forwards	56.7 ± 16.4	4948 ± 1370	88 ± 8	-	-	-
	NRL adjustables	82.8 ± 8.9	7973 ± 1160	96 ± 8	-	-	-
	NRL backs	85.8 ± 3.9	7381 ± 518	87 ± 6	-	-	-
Varely et al. [41]	NRL	64.9 ± 18.8	6276 ±1950	96 ± 16	5950 ± 1845	327 ± 168	11.4 ± 5.9
Twist et al. [62]	ESL forwards	57.9 ± 15.8	5733 ± 1158	102 ± 14	-	-	-
	ESL adjustables	69.7 ± 23.4	6766 ± 1495	104 ± 27	-	-	-
	ESL backs	83.9 ± 12.9	7133 ± 1204	86 ± 11	-	-	-
Waldron et al. [8]	ESL forwards	44.2 ± 19.2	4181 ± 1829	95 ± 7	1723 ± 743	513 ± 298	-
	ESL adjustables	65.2 ± 12.4	6093 ± 1232	94 ± 8	2365 ± 667	907 ± 255	-
	ESL backs	77.5 ± 12.3	6917 ± 1130	89 ± 4	3262 ± 505	926 ± 291	-
Gabbett [58]	NYC forwards	52.3 ± 25.4	4866 ± 2383	93 ± 9	4641 ± 2315	225 ± 90	7.5 ± 3.5
	NYC adjustables	71.3 ± 14.0	6920 ± 1481	97 ± 10	6562 ± 1297	320 ± 17 6	11.3 ± 6.6
	NYC backs	75.5 ± 15.8	7172 ± 1377	96 ± 11	6767 ± 1262	452 ± 113	8.1 ± 1.4

Table 2.1. Continued.

Study	**Group**	**Playing time (min)**	**Distance (m)**	**Distance ($m \cdot min^{-1}$)**	**LSA (m)**	**HSR (m)**	**RHIE bouts (no.)**
McLellan & Lovell [61]	NYC forwards	-	4774 ± 564	82 ± 5	-	-	-
	NYC backs	-	5768 ± 765	74 ± 11	-	-	-
Waldron et al. [64]	Elite Under-15 players	53.8 ± 12.1	4479 ± 898	84 ± 6	-	-	-
	Elite Under-16 players	57.2 ± 12.0	5181 ± 1064	91 ± 5	-	-	-
	Elite Under-17 players	73.0 ± 14.7	6392 ± 1239	91 ± 3	-	-	-
Gabbett [72]	QC top 4 teams	69.3 ± 19.6	5822 ± 1654	86 ± 8	5475 ± 1516	348 ± 186	10.9 ± 5.1
	QC middle 4 teams	70.2 ± 19.0	5823 ± 1616	85 ± 7	5461 ± 1494	362 ± 193	10.6 ± 5.3
	QC bottom 4 teams	68.3 ± 18.4	5880 ± 1583	87 ± 7	5547 ± 1481	334 ± 166	11. 4 ± 5.7
McLellan & Lovell [61]	QC forwards	-	6701 ± 678	89 ± 8	-	-	-
	QC backs	-	7505 ± 627	94 ± 8	-	-	-
Duffield et al. [31]	Senior non-elite players	74 ± 10	5585 ± 1078	75 ± 14	4923 ± 935	661 ± 225	-
Johnston et al. [30]	Senior non-elite players	68.8 ± 11.2	5919 ± 872	82 ± 7	5562 ± 828	358 ± 125	1.6 ± 1.5
Gabbett [60][a]	Junior non-elite players	32.7 ± 8.4	2673 ± 650	83 ± 12	2529 ± 619	144 ± 82	4.5 ± 2.5

Data are reported as mean ± standard deviation. NRL = National Rugby League (elite); ESL = European Super League (elite); NYC = National Youth Competition (junior elite); QC = Queensland Cup (semi-elite). WR = wide-running. HSR = High-speed running; LSA = Low-speed activity; RHIE = Repeated-high intensity effort (classified as 3 or more high acceleration, high speed or contact efforts with ≤21 s between efforts). [a] Games were 40 minutes in duration.

2.3.3 High-Speed Running

Players are required to perform high-intensity activities at critical periods of a match [55, 72, 76]. Forwards cover the least distance at high speeds (513 ± 298 m) compared with adjustables (907 ± 255 m) and outside backs (926 ± 291 m) [8] (Tabl e 2.1). The majority of these high-intensity efforts occur over short distances, with 75-95 runs over less than 10 m, depending on position, and as few as 1-3 runs over a 50 m distance [5]. Outside backs perform significantly more high-speed runs over 10-20 m than props, and over 20-30 m than adjustables and props [5]. Like soccer [78], there is variation in high-speed (Coefficient of variation [CV] = 14.6%) and very-high speed running (CV = 37.0%) between games [79]. However, how much of this variation is due to various match factors, such as opposition, or the reliability and validity issues surrounding the GPS devices used is unknown [80]. Despite this, it is clear that workloads between players and matches vary; coaches should be mindful of this when prescribing training following each game.

There is little difference in the amount of high-speed running performed by winning and losing teams [55, 63, 72]. However, it is unclear whether there is a difference in how players achieve these distances (e.g. good kick chase in winning teams *vs.* covering line breaks in losing teams). It appears less successful teams are equally equipped to perform high-speed running efforts, but perhaps not able to recover as quickly [55, 63]. However, further evidence from semi-elite players suggests that when compared to successful teams, less successful teams can maintain total distance and high-speed running to a similar extent following peak 5 min periods [63]. However, whilst these players may be able to maintain running efforts, they are unable to maintain collisions and repeated high-intensity effort (RHIE) bouts [63], which are particularly important [25, 76] and demanding [9] components of match-play. High-speed running during match-play in junior elite players does also not appear to indicate success. Waldron et al., [64] reported that during match-play, in the Under-15 and -17 age groups, selected players performed less high-speed running per minute of match-play. In Under-16 players, selected players covered slightly more high-speed running per minute of match-play, but the difference was only trivial. In spite of performing greater relative distances at high-speeds, later maturing players found themselves unselected. The amount of high-speed running players perform varies depending on field position and is 6-8 times higher when defending in the opposition's 30 m zone, compared to the other two-thirds of the field [25].

Although this evidence suggests that players require the capacity to perform large amounts of high-speed running during short periods of match-play and recover at a high relative intensity, it is apparent that high-speed running does not clearly discriminate between playing rank. It is likely that the ability to perform other, more specific match activities can distinguish between successful and less successful players.

2.3.4 Sprinting

The distribution of sprints is similar to high-speed runs, with almost 40% of sprints performed over 6-10 m, and 85% being shorter than 30 m. Furthermore, only 1.4% of sprints are deemed high velocity (>7.0 $m.s^{-1}$) with the remainder comprised of low (≤1.11 $m.s^{-2}$), moderate (1.12-2.77 $m.s^{-2}$), and high (≥2.78 $m.s^{-2}$) acceleration efforts [4]. Players perform a range of different activities prior to sprinting, with standing (24.3%), and forward walking (28.1%) being the most common [4]. Training acceleration across all positional groups by performing short sprints, typically over 0-20 m from a number of starting positions is vital. Longer sprints focusing on peak velocity are also important for the outside backs [4, 8].

2.3.5 Repeated High-Intensity Efforts

Given the frequency of sprints (>7 $m{\cdot}s^{-1}$) performed over a game (35 ± 2 irrespective of playing position) [4], it could be thought that repeated-sprint ability (RSA) is an important attribute. Research from field hockey reported that the majority of sprints either occurred with less than 21 seconds or more than 2 minutes between each sprint [81]. As such, repeated-sprint bouts are defined as 3 or more sprints with less than 21 seconds between each sprint [81]. However, these bouts rarely occur in rugby league competition, with players only performing 1 ± 1 (range: 0-3) repeated-sprint bout during a match [4, 6]. This could be due to the infrequency of high-velocity sprints [4], as well as the numerous physical collisions that players perform over a match [9, 10, 47]. Wide-running forwards perform the greatest number of collisions (47 ± 12), followed by hit-up forwards (36 ± 8), adjustables (29 ± 6), and the outside backs (24 ± 6) [10]. However, when expressed relative to playing time, the greatest frequency of collisions occurs in the hit-up forwards (0.58 per min) [2, 5]. Whilst repeated-sprint bouts may be important to non-contact sports [81], they are unlikely to reflect the most demanding passages of play in contact sports due to the exclusion of other high-intensity activities such as high-speed running, accelerations, and collisions. Indeed, the addition of contact to repeated-sprints results in greater reductions in sprint performance [9]. Therefore, recognising repeated-sprint bouts as the 'worst-case' demands or exclusively training repeated-sprint ability is likely to leave players underprepared for the most demanding passages of match-play [9, 76].

Based on these shortfalls, all high-intensity activities (collisions, high-speed running, and maximal accelerations) have since been incorporated into repeated-sprint bouts to truly reflect the 'worst-case scenarios' termed RHIE bouts [2, 4, 76]. More specifically, a RHIE bout, adapted from the definition of repeated-sprints [81], is defined as 3 or more maximal acceleration, high speed, or contact efforts with less than 21 seconds between each effort [2]. Research suggests that in the NRL, players perform in the region of 9-14 RHIE bouts per match (Table 2.2) with little difference between positions [2, 4, 55, 58]. RHIE bouts occur during important passages of play, suggesting that the ability, or inability, to perform these bouts may significantly influence the outcome of a game [55, 76]. The greatest frequency of RHIE bouts occurs when players are defending in their 0-30 m zone (ES = 0.75-0.85) [25], with 70% of RHIE bouts occurring within 5 minutes of a try being scored [76]. Moreover, winning teams perform more RHIE bouts, and more efforts per bout than losing teams [55]. At the elite level, the running demands are similar between NRL and National Youth Competition (NYC) players, whereas the RHIE demands are greater during NRL competition [58]. In addition, elite players are more likely to perform a greater number of efforts per RHIE bout and have less recovery between bouts than their semi-elite counterparts [65]. Taken together, it appears vital that both senior and junior players are conditioned for the most demanding RHIE bouts experienced during match-play.

When it comes to designing RHIE drills for training, it is important to consider the worst-case demands of competition. Black & Gabbett [65] reported on the most demanding RHIE bouts for elite and semi-elite players. In elite players, the most demanding RHIE bout was performed by a hit-up forward and included 13 efforts over 120 seconds (4 tackles 9 acceleration efforts), with a mean recovery time of 5 seconds between efforts. In semi-elite players a wide-running forward performed 8 efforts in a bout over 62 seconds (8 sprints and acceleration efforts) with a mean recovery time of 7 seconds between efforts [65]. This research highlights that RHIE bouts are complex in nature and comprised of different activities, effort numbers, recovery between efforts, and recovery between bouts. There are a number of studies that document the nature of these RHIE bouts [2, 58, 65, 76] which are summarised in Table 2.2. This information can be used by conditioning staff to develop position specific RHIE drills to replicate the 'worst-case scenarios' of competition.

Table 2.2. Repeated high-intensity effort demands of NRL competition. †

	Hit-up forwards	Wide-running forwards	Adjustables	Outside backs
Total bouts (no.)	8-12	10-12	6-14	5-15
Maximum bout duration (s)	120	64	92	49
Mean efforts per bout (no.)	4-6	4-6	4-6	4-6
Maximum efforts per bout (no.)	13	6	10	7
Mean effort duration (s)	1.2-2.1	1.2-1.8	0.9-1.6	1.0-1.5
Maximum effort duration (s)	4.9-6.0	4.9-5.6	3.9-4.7	5.1-5.5
Effort recovery (s)	6.3-6.4	5.9-6.3	5.9-7.0	5.9-6.3
Bout frequency	1 every 4.8-7.8 min	1 every 5.5-6.3 min	1 every 5.2-8.0 min	1 every 4.7-9.1 min
Minimum bout recovery (s)	42	42	55	55

† Data from Austin et al. [76]; Black & Gabbett [65]; Gabbett [58]; Gabbett et al. [2].

2.3.6 Activity Cycles

A recent study assessed 5 minute periods of competition in NRL and NYC adjustables [77]. During the peak period for total distance, the ball was in play for significantly longer (peak: NRL = 251 s, NYC = 241 s; subsequent: NRL = 175 s, NYC = 185 s; mean: NRL = 184 s, NYC = 175 s); players covered greater total distance; and had a greater skill rating, compared with the subsequent and mean 5 minute periods. While this study provides some information on the most demanding 5 minute periods of play in adjustables, only using 5 minute periods may not capture, and therefore underestimate the most demanding passages of play. Indeed, the longest time the ball is in play for in NRL and NYC matches has been reported as over 11 minutes [1]. The average longest activity cycle is greater in the NRL (318.3 ± 65.4 s vs. 288.9 ± 57.5 s) and there is a smaller proportion of short duration activity cycles (<45 s) than longer activity cycles (>91-600 s) compared with NYC matches[1]. Furthermore, Top 4 NRL teams have a greater proportion of long activity cycles than Bottom 4 NRL teams [82], and in the 5 min period following the peak 5 min period, successful teams have longer ball-in-play cycles than less successful teams [63]. Activity cycles of ‘State-of-Origin’ competition between Queensland and New South Wales even exceed those of NRL matches, with a greater proportion of long duration activity cycles [83]. Collectively, these data highlight the importance of performing prolonged high-intensity exercise (> 10 minutes) and the ability to recover during short rest periods.

2.3.7 Phase of Play

The demands of defending are generally higher than attacking with greater total distance (106 $m \cdot min^{-1}$ vs. 82 $m \cdot min^{-1}$), low-speed distance (104 $m \cdot min^{-1}$ vs. 78 $m \cdot min^{-1}$), collision frequency (1.9 per min vs. 0.8 per min), and RHIE frequency (1 every 4.9 min vs. 1 every 9.4 min) [25]. Moreover, there may be stages when players are required to defend for a number of sets (e.g. concede a penalty, or drop-out) at these elevated intensities. Coupled with the fact that fatigue causes reductions in tackling technique [84], the ability or inability to maintain these elevated match intensities, and minimise reductions in tackling technique, could determine whether a try is conceded. Although the demands of attack are lower than defence [25], players are required to maintain possession of the ball to create try-scoring opportunities, which may occur under high levels of fatigue [77]. Therefore, it is important that players are prepared for the most demanding running and contact demands of competition, whilst being able to maintain skill execution in both attack and defence. Given the increased physical demands of defence and the large physical cost associated with collisions [9, 47], teams that have performed large amounts of defence during a game may require additional recovery following competition. The emphasis on recovery may be increased further if the match was won, as these matches are associated with greater physical demands [55].

2.3.8 Pacing and Match Fatigue

Over the course of a game, players experience transient fatigue [5, 15, 16, 77] and display pacing strategies to permit the completion of the game whilst remaining in a reasonable physical state [15, 16]. Whilst low-speed activity is maintained over a game, there are reductions in high-speed running of 20.0 ± 21.4% and 30.5 ± 20.2% in the final 20 minutes of each half [5], indicative of fatigue [85, 86]. Furthermore, adjustables exhibit reductions in distance covered and skill involvements in the final 10 minutes of the match [77]. This suggests that fatigue develops over the course of a game and results in reductions in physical and technical performance towards the end of each half of match-play. Utilising interchange players in the closing minutes of each half may attenuate the decline in match intensity [15, 16].

Although fatigue may manifest towards the end of each half, players also employ pacing strategies depending on their role within the match (whole-match vs. interchange players) [15, 16]. Whole-match players only show reductions in high-speed running in the final quarter (~21%) [16], which is in accordance with others [5], highlighting the gradual onset of fatigue. Furthermore, whole-match players appear to employ a pacing strategy to manage energy expenditure so they can adequately complete game tasks, yet finish the match in a reasonable physical state. On the other hand, interchange players initially pace at a higher intensity than whole-match players [15, 16]. Waldron et al. [16] found that during the first interchange bout, players were able to maintain a greater match intensity than whole-match players for approximately 15 minutes. However, during their second bout, interchange players paced at a similar intensity to whole-match players so they maintain enough energy to produce an ‘end-spurt’ in the final minutes of the match [16]. Interchange players appear to cover greater distance per minute and greater distances at low speeds, as well as greater RHIE bout frequency than whole-match players [15]. Collectively these data highlight that pacing occurs during rugby league match-play and interchange players set higher pacing strategies than whole-match players. If the aim of the interchange is to increase match-intensity, coaches should acknowledge that the interchange player may only be effective for the first 15 minutes (depending on their individual physical capacity and the nature of the game) [16]. Despite this, more research is required in order to ascertain whether interchange players set different pacing strategies depending on the length of time they are likely to be on the field.

Pacing strategies also differ depending on match outcome for both whole-match and interchange players [15]. Whole-match players in winning teams maintain greater match intensity and cover greater distances at low-speeds compared to players on losing teams [15], which is in accordance with others [55]. There is no difference in interchange players' match intensity between winning or losing teams, except for the final quarter, where losing players produce an 'end-spurt', most likely in an attempt to force a positive result for their team [15]. These studies [15, 16] highlight that match demands differ between whole-match and interchange players, as well as winning and losing teams. Therefore, when conditioning interchange players a greater emphasis can be placed on short, high-intensity exercise bouts. More information is required as to the effect physical qualities have on pacing strategies in rugby league players.

2.4 Physiological Responses during Match-Play

Since the previous review [51], the internal load during competition has been assessed using heart rate [8, 16, 64]. Elite players show average heart rates similar to those from semi-elite players [87], with little difference between the backs (83.5 ± 1.9%), adjustables (81.5 ± 4.1%), and forwards (84.1 ± 8.2%) [8]. Heart rate responses of elite Under-16 and -17 players are also similar to those reported for senior players (82.1-83.2%), with slightly lower responses in Under-15 players (78.8-79.7%) [64]. Average heart rate is reduced in elite players in the second half which is likely to be explained by second-half reductions in playing intensity [16]. Although the relative intensity of a match appears to be similar between positional groups, the internal load, highlighted by training impulse is greater in the outside backs (279.4 ± 71.8 Arbitrary Units [AU]) than the forwards (198.3 ± 82.3 AU), but not different to the adjustables (270.6 ± 63.5 AU) [8]. Whilst greater playing times experienced by the adjustables and outside backs could explain these differences [8], greater overall and high-speed running distances also heavily influence the rating of perceived exertion (RPE) [88].

2.5 Physical Qualities

Based on the complex demands of the game, players require a broad range of physical qualities [89, 90]; normative data are highlighted in Tables 2.3 and 2.4.

2.5.1 Body Composition

Due to the physical contact during a match, body mass and in particular lean mass are important (Table 2.3) [91]. Forwards are heavier, and have greater skinfold thickness than other positional groups [90, 92-95]. Recent studies report no difference in body mass between elite and semi-elite players [23, 96] but lower skinfold thickness as playing standard increases [96, 91, 97, 23, 98], indicating greater lean mass in elite players. Low skinfold thickness is one of the most important discriminators between national and regional junior [91], and selected and non-selected senior elite players [23]. Furthermore, low skinfold thickness is associated with improved vertical jump (r = -0.345), 30 m sprint (r = 0.417), 505 agility (r = 0.391), maximal aerobic power ($\dot{V}O_2$ max) (r = -0.464) [99], and career progression [100]; conversely, high skinfold thickness is associated with fewer playing minutes in elite players [23]. These data indicate that whilst high body mass is important, low body fat is vital so that performance is not compromised. This should be developed from an early age in order to improve performance, as well as the wellbeing of players who may not continue to play the game at a senior level. With appropriate training and nutrition, players can expect to see gains in body mass and reductions in fat mass during the pre-season [94], however these gains may be difficult to maintain over the competitive period [101, 102], which may be explained by reduced training load during this time [103].

Table 2.3. Anthropometric characteristics of rugby league players by playing standard. †

Playing standard	Height (cm)	Body mass (kg)	∑ 7 Skinfolds (mm)
Senior elite [23, 96, 104]	183.9-184.2	94-97.6	47.0-60.8
Senior semi-elite [24, 96]	183.1	93.4-98.0	65.3
Senior non-elite [75, 105]	174.0-180.1	78.0-92.2	83.2-90.7
Junior elite [73, 90, 91, 95, 98, 100, 106, 107]	171.0-182.0	75.2-95.1	64.3-68.5
Junior non-elite [73, 91, 97, 98]	169.6-176.0	69.7-76.3	75.1-76.4

† Data are presented as means; ∑ = sum of.

Table 2.4. Physical performance standards of rugby league players by playing position and standard. †

Playing standard	Yo-Yo IRT (m)	Predicted $\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	10 m sprint (s)	40 m sprint (s)	505 agility (s)	Squat 1RM (kg)	Bench 1RM (kg)	VJ (cm)	SJ peak power (W)	BT peak power (W)
Senior elite	1656-1789	54.9-55.9	1.60-1.78	5.19-5.32	2.20-2.26	171-201	125-143	37-65	1709-2227	341-635
Senior semi-elite	1506-1564	51.9-53.2	1.60-1.74	5.13-5.29	2.27-2.32	150-155	111-144	61-69	1701	515-694
Senior non-elite	1080	45.0-47.6	1.82-2.19	5.69-6.14	2.34-2.69	145	105-134	41-62	-	506
Junior elite	1440-1488	46.4-51.7	1.61-2.06	5.15-5.83	2.30-2.47	133-145	101-133	44-53	1897	-
Junior non-elite	1340	32.1-50.6	1.79-1.95	5.52-5.93	2.31-2.54	145	70-115	43-58	1315-1552	255-554

† Data are presented as means; IRT = intermittent recovery test (level 1); 1RM = 1 repetition maximum; SJ = Squat Jump; BT = Bench Throw Data taken from [23, 24, 73, 75, 90-93, 100, 97, 96, 106, 104, 108-126].

2.5.2 Speed and Acceleration

The majority of sprints performed during competition are over short distances (e.g. 0-20 m), as such, acceleration is a key attribute [4]. Acceleration is particularly important for forwards, who have the greatest proportion of short sprints [4]. Older studies (pre-2008) indicate no difference in speed qualities between standards [75, 93, 119], whereas more recent reports (post-2008) find elite players to be faster [23, 91, 96, 97], which may be due to advancements in the training methods of elite players (Table 2.4). Furthermore, 20 m sprint speed is an important discriminator between national and regional junior players [91] and between junior players who progress to elite and amateur levels [100]. Backs are significantly faster than forwards, especially over longer sprints [90, 108]. Developing speed, and in particular acceleration, from an early age should be a priority.

2.5.3 Agility

The ability to change direction at speed in rugby league is thought to be important [4, 109]. Despite this, there appears to be little difference in pre-planned change of direction speed performance between senior playing standards [93, 96, 109, 127], or positions [128]. However, in juniors, national players outperform regional players on the 505 agility test [91] and agility may influence long-term career progression [100]. In juniors, props are significantly slower than the other positional groups [99]. Although pre-planned agility is unable to distinguish between playing standard and position in senior players, when players are required to change direction in response to a sport-specific stimuli (i.e. reactive agility), there are clear differences [109, 127, 129]. Reactive agility performance is poorly correlated with 505 or L-run agility test performance [109]. This suggests that factors other than change of direction speed (e.g. visual scanning, anticipation, pattern recognition, and situation experience) influence reactive agility performance and that they are distinct and separate qualities. With this in mind, it may be important for junior players to first master the ability to change direction and the specific movement skills required; as they develop, they need to be able to make decisions and change direction in response to specific stimuli (i.e. reactive agility).

2.5.4 Muscular Strength and Power

As discussed in a recent review paper [130], muscular strength and power are vital for success in contact sports. Upper and lower-body maximal strength and power have consistently been shown to increase with playing standard [23, 73, 118-121, 131, 132]. Muscular strength has been most commonly assessed with the back squat for the lower-body, and bench press for the upper-body, either testing 1 repetition maximum (RM) [116, 133-135] or 3RM [24, 115, 122]. Elite players have a 1RM back squat ranging from 170-201 kg (relative strength: 1.78-2.05 $kg \cdot kg^{-1}$) [116, 119] compared to 150 kg (1.64 $kg \cdot kg^{-1}$) for semi-elite players [119]. Furthermore, 3RM squat was significantly greater in selected semi-elite players, compared with non-selected players [24]. Muscular power is typically assessed in the lower-body via vertical jump height [23, 73-75, 93, 96, 98, 113, 114, 117, 128] or peak power from jump squats [117, 119, 120, 122, 131] and bench throws for the upper-body [120-122, 131]. Some studies report increases in vertical jump height with playing standard [23, 98, 114], whereas others do not [75, 96, 113]. Despite this, jump squat and bench throw peak power consistently increases with playing standard [117, 119, 121, 122, 131]. Forwards tend to be stronger and more powerful than the backs in absolute terms, but not when expressed relative to body mass [117]. Baker and colleagues reported that stronger players produce greater power outputs during the bench throw [121], and strength is associated with power production [122]. Increasing lower-body strength via multi-joint exercises (e.g. back squat) appears to translate into improvements in sprint speed over 0-20 m [116] and jump squat performance [136]. This is not surprising given that power is the product of force and velocity, and if force generating potential increases, then so will power. Despite this, low strength individuals still possess the ability to improve power, highlighting that adaptations other than maximum strength are important for improving power [136, 137]. With this in mind, specific programmes need to be implemented using multi-joint exercises to maximise gains in strength and power.

2.5.6 Aerobic Power

Given the duration of a rugby league match, the distances covered at low-speeds [2], and the need for rapid recovery following high-intensity exercise [138], it would be expected that well-developed aerobic power is important for performance. In accordance with the previous review [51], senior elite players have well-developed $\dot{V}O_2$ max in the range of 54.9-55.9 $ml.kg^{-1}.min^{-1}$ [23, 104] with little difference between positions [74, 93, 128], and increasing with playing standard [23]. Despite this, $\dot{V}O_2$ max does not relate to any measure of match performance [28, 104, 124], which questions the utility of assessing $\dot{V}O_2$ max in an applied setting. However, in junior players, $\dot{V}O_2$ max is the strongest discriminator between playing rank [91], and is greater in players that progress to professional levels [100]. This suggests, that a well-developed aerobic capacity is vital at a young age, before developing more specific qualities, such as high-intensity running and RHIE ability, that appear more important for performance [28].

2.5.7 High-Intensity Running Ability

There are passages in play where players are required to perform large amounts of high-speed running in a short period of time [25, 77]. As such, well-developed high-intensity running ability is required in order to compete during these periods. Methods for testing this quality are inconsistent; some studies have used the Yo-Yo Intermittent Recovery Test [24, 110, 139], while others have used a prolonged high-intensity running ability test [23, 28, 104]. Gabbett and colleagues reported no difference in prolonged high-intensity running ability, and RSA between starters, interchange, and non-selected players [23]. Atkins et al. [110] found no difference in Yo-Yo intermittent recovery test (IRT) (Level 1) distance between elite (1656 ± 403 m) and semi-elite players (1564 ± 415 m). In contrast, distance covered on the Yo-Yo IRT (Level 1) was greater in selected (1506 ± 338 m) compared with non-selected (1080 ± 243 m) semi-elite players [24]. In addition, greater high-intensity running ability is associated with greater playing minutes ($r = 0.32$) [23], as well as greater total and high-speed distance [28]. Whilst high-intensity running ability is a key attribute, the lack of differences between playing standard may reflect that these measures of anaerobic endurance fail to incorporate any form of contact, and therefore do not adequately replicate the demands placed on players. Indeed, the lack of association between aerobic fitness (Yo-Yo IRT and multi-stage fitness test) and RHIE performance highlights this point [24, 126, 140]. As such, two attempts has been made to develop a specific RHIE test [126, 140]. Although the test developed by Austin [140] detected changes in RHIE performance, sprint time was the only dependent variable used, and did not take into account changes in tackle technique during the test. As such, Gabbett and Wheeler [126] developed a test that in addition to sprint time measured 2D PlayerLoad™ (to highlight the non-running, contact component of the test). They found that this test was valid as it discriminated between first and second grade players [126], although it was not determined whether players that perform well on this test perform more RHIE bouts during match-play. It was also reported that players with greater initial speed had a higher average speed over the sprints on the test, and players with greater maximum repetition triceps dips maintained a higher overall 2D PlayerLoad™. This suggests that acceleration and upper-body strength endurance may positively affect RHIE ability. Despite this, given the complex nature of RHIE bouts, and the poor association with a number of physical qualities [24, 126] it is likely that a number of qualities share small associations with RHIE ability. Although future research is required, it could be speculated that in order effectively develop this unique ability, players need to engage in regular RHIE specific training that replicates the worst-case scenarios of competition.

2.5.8 Technical Skills

It is clear that technical skills are also vital for successful rugby league performance with elite players having superior tackling technique [23, 141], dual-task draw and pass proficiency [23, 142, 143], and anticipatory skill [73]. Furthermore, better tackling technique results in fewer missed ($r = -0.74$) and more dominant tackles ($r = 0.78$) during competition [141]. Despite this, the reliability of technical assessments, at least in junior players, has been questioned; it is important that when assessing a squad, the same expert assessor is used for all players [144]. Draw and pass performance (single-task) does not distinguish players of different standard, whereas, under dual-task conditions, elite players are better able to maintain performance [142, 143]. These findings suggest that the attentional demands of performing a successful draw and pass are lower (or alternatively, the skill is more automated) in elite performers. Therefore, when these players are faced with this situation in a match, under pressure and fatigue, they are more likely to deliver a successful outcome. Indeed, greater off-field performance on these tasks is associated with a greater number of try assists, line break assists, fewer missed tackles, and more dominant tackles [104, 141]. As such, it is important for players to improve skills under single- and dual-task conditions. Fatigue also appears to impact on skill performance, with technical performance being reduced following the 5 minute peak periods of NRL and NYC matches in the adjustables positional group [77]. Given that success in a game is governed by the number of tries scored or conceded, improving match-specific skills through training in both fatigued and non-fatigued states is likely to transfer to improvements of these skills during match-play.

2.6 Physical Qualities, Performance and Injury

Given the demanding nature of competition, it is not surprising that physical qualities influence match performance [104]. Sprint performance over 40 m is associated with evasive skills, such as beating a player (r = -0.48), offloading (r = -0.45) [75], and tackles completed during match-play (r = 0.44) [104]. Force generated over a 10 m sprint is positively associated with successful ball carries in junior players [124]. Initial acceleration is associated with improved average speeds on a RHIE drill (r = 0.75) [126]. Reactive agility is associated with evasive skills and line break assists (r = 0.29) [104, 75]. Lower-body relative power is associated with sprint performance over 5, 10, and 30 m [115] and dominant tackles during match-play (r = 0.27) [104]. Lower-body strength appears vital for performance, with a greater 3 RM squat leading to greater distances covered at both low and high speeds, as well as a greater number of RHIE bouts during match-play [24, 139]. It is likely that strong players are better able to utilise the stretch-shortening cycle [49], resulting in less neuromuscular fatigue [50] when moving at high-speeds or effecting tackles, allowing them to execute these high-intensity activities more frequently [139]. Improving back squat strength appears to translate into improvements in sprint performance, particularly over 5 m where large forces are required during initial acceleration [116]. Based on this information, developing speed, agility and lower-body strength and power in rugby league players is vital for successful performances.

Given the high frequency, tackling is arguably one of the most important skills required of rugby league players. The greatest predictors of tackling technique in high-performance players are playing experience (ES = 1.59; r = 0.70) and lower-body power (ES = 0.49; r = 0.38) [96]. In addition, skinfold thickness (ES = 1.30 to 1.81; r = -0.59 to -0.68), and acceleration (ES = 0.82 to 2.30; r = 0.41 to 0.60) are also associated with tackling technique [96, 111]. Whilst playing experience is likely to directly improve tackling technique, greater acceleration, lean mass, and lower-body power could allow a player to generate more force in the tackle, potentially leading to more dominant tackles [141]. Well-developed agility (r = 0.68) and aerobic power (r = -0.63) are associated with smaller, fatigue induced decrements in tackling technique [84]. This is likely to reduce the number of ineffective tackles in a match, particularly in the final stages of each half when fatigue is evident [16].

As highlighted earlier, the ability to perform repeated-efforts is vital for performance [25, 55, 76]. Players with well-developed prolonged high-intensity running ability spend more time on the pitch, and cover greater total distances at both low- and high-speeds [28], and recover faster following match-play [139]. However, players with poor prolonged high-intensity running ability perform more collisions, and RHIE bouts [28]. This highlights that while high-intensity running ability is vital for running performance and minimising post-match fatigue [139], it does not translate to RHIE performance where the ability to perform contact efforts is vital. As such, it is clear that while running ability needs to be developed, specific contact and running drills must also be incorporated into training.

Skill qualities do not appear to influence injury risk [145], whereas a number of physical qualities do [146, 147]. Faster 10 and 40 m sprint times, greater maximal aerobic power, high-intensity running ability, body mass, and upper-body strength are all associated with lower injury risk [146, 147]. Although speculative, there are numerous factors that could explain these relationships. Firstly, contact injuries are the most common type of injury sustained in rugby league [148, 149]. Therefore, light players will produce less momentum when carrying the ball into the defensive line and slow players are more likely to be tackled than faster players [75], both of which are likely to increase injury risk. Secondly, players with lower aerobic power are likely to exhibit greater decrements in tackling technique [84], which in turn could increase contact injury risk. Thirdly, players with greater upper-body strength are more likely to 'win' the tackle in both attack and defence, potentially minimising injury risk. A broad range of physical qualities, such as speed, strength, and aerobic power need to be developed to minimise injury risk.

2.7 Post-Match Fatigue

Players experience immediate and delayed symptoms of fatigue that persist for a number of days following match-play. Studies have reported impairments in whole body neuromuscular function [27, 30-34]; increases in markers of skeletal muscle damage [27, 30, 34-36, 139], and reductions in perceived wellbeing [27, 30, 32] following rugby league matches. Due to the recovery time between matches, typically 5-10 days, coaching staff need to be mindful of the recovery time course in order to prepare optimally for the subsequent match.

The majority of studies quantifying post-match fatigue in rugby league players have utilised the countermovement jump (CMJ) to detect impairments in neuromuscular function [27, 30-34, 150, 139]. Following competition there are transient reductions in neuromuscular function typically lasting 24-48 hours, evidenced by decreases in peak power and jump height [27, 33, 34]. Peak force appears less sensitive at detecting fatigue, showing little change following both single games [34] and an intensified competition [30] As such, lower-body fatigue variables including a velocity component, such as peak power offer high reliability and sensitivity for detecting changes in neuromuscular function [151]. Training aimed at developing speed and power qualities should be avoided for 48 hours after competition.

There is evidence that upper-body muscle fatigue occurs following matches [30, 139]. Plyometric push-ups have been shown to offer good reliability in rugby league players [47]. Various studies have shown reductions in power and force following competition [30, 139, 150] and small-sided games [47]. Furthermore, upper-body fatigue is only evident following physical contact [47]. These findings indicate that physical contact is largely responsible for upper-body fatigue following training and competition; assessing lower-body fatigue alone may underestimate the fatigue response.

The most effective way to determine fatigue is to utilise direct tests of muscle function. Despite this, numerous studies have utilised blood or plasma creatine kinase (CK) as an indirect marker of muscle damage in an attempt to understand the underlying physiological mechanisms [27, 30, 34-36, 139]. Under normal, homeostatic conditions, CK is located within the myofibrils [152]; exercise induces varying degrees of mechanical muscle damage [153] which is thought to cause the release of intracellular components, including CK, into the extracellular fluid [154, 155]. Current evidence highlights CK is elevated immediately post-match, with a peak at around 24 hours after competition [27, 34-36], and may remain elevated for up to 120 hours following competition [34, 35], long after neuromuscular function has recovered [33, 35]. Physical collisions appear to be largely responsible for these increases in CK, with strong correlations between increases in CK and the number of collisions performed [27, 36]. Furthermore, larger increases in CK were seen following small-sided games involving contact, compared with non-contact small-sided games [47]. Although CK is widely used as a marker of muscle damage, its utility has often been questioned [156, 157]. However, recent research from rugby league [30, 150] and Australian football [40] suggests that high blood CK, indicative of muscle damage, is associated with reductions in match performance. In spite of this, regular assessment of CK with players is difficult, given the cost, time, variability in responses, and invasive nature of the tasks [158]. More information regarding monitoring fatigue in rugby league can be found in this review [158].

2.8 Conclusions

The aim of this article was to offer a comprehensive and updated review of the literature regarding applied sport science in rugby league. There are now numerous studies that highlight the demands of the game in great detail from elite to non-elite competitions, indicating that as playing standard increases so too do the demands of the game, and in particular the RHIE demands. Winning in rugby league is associated with significantly greater match intensities, and repeated-effort demands. Lower-body strength and power, as well as speed are positively associated with match performance and match-specific skills. High-intensity running ability is related to greater running performance during competition, but not RHIE performance. As such, players need to train specifically to replicate the most extreme RHIE demands of competition. As well as physical qualities, a number of technical skills also impact on successful tackles, line break assists, and try assists.

Significant fatigue and muscle damage occurs following matches. Reductions in muscle function and perceptual fatigue typically return to baseline within 48 hours of competition, although CK can remain elevated for up to 5 days. Well-developed high-intensity running ability and lower-body strength may reduce post-match fatigue. Markers of fatigue are exacerbated during periods of intense competition. Physical contact is largely responsible for increases in CK and upper-body fatigue. Increased blood CK prior to competition is associated with reductions in high-speed running and RHIE bouts. As such, players need to have well-developed physical qualities and allow sufficient time for recovery between games in order to maintain playing performances.

It is clear that in rugby league, physical and technical qualities are closely linked to successful performances. In junior players, low skinfolds, $\dot{V}O_2$ max, agility and speed appear the most important physical qualities, and have a strong association with long-term career progression. In senior players, muscular strength and power, low skinfolds, high-intensity running ability, reactive agility, and acceleration are vital to performance. Tackling technique and dual-task draw and pass ability appear the most important technical skills. Ultimately, these data highlight the need for specific training that aims to develop both physical and technical qualities.

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Chapter 3

Reliability of Dependent Variables

3.1 Introduction

Test-retest reliability refers to the reproducibility of an observed score when the trial is repeated on an individual. The reliability in the test is often referred to as error or 'noise'; smaller error highlights a more precise test, making it easier to detect meaningful changes in a variable [159]. It is important to determine both the within- and between-day retest reliability because often changes in a certain variable may be assessed a number of times in one day or a number of times over different days.

There are a number of different statistical approaches that can be used to determine reliability of a measure. In this thesis, the typical error of measurement (TE) as a coefficient of variation, as well as intraclass correlation coefficients (ICC) were used. Firstly, the TE represents the standard deviation of an individual's repeated measurements. This is important because it is a measure of the within-subject variation, which allows us to determine how precise a measure is, and therefore the size of change needed to be determined practically important. Secondly, whilst the ICC does not give any indication of the magnitude of error in the test, it tells us whether the rank order is maintained within a group following repeated trials [159]. This is important when scientists assess changes in performance within a group of individuals.

The dependent variables used in this thesis were largely similar between studies. The within- and between-day retest reliability is reported within this chapter for both within- subject reliability (TE) and the between-subject reliability (ICC). Determining the reliability of the dependent variables was important in order to ascertain whether any changes in these variables were meaningful rather than 'noise' in the variable.

3.2 Methods

3.2.1 Countermovement Jump

In each study, the countermovement jump (CMJ) was used to measure lower body muscle function. The same Kistler 9290AD Force Platform (Kistler, USA) connected to a laptop (Acer Aspire 2930, Acer, UK) running software provided by the manufacturer (QuattroJump, Kistler, USA) was used during the thesis. In order to determine the within-day retest reliability of the CMJ, 41 semi-professional rugby league players (age 24.2 ± 3.4 years; height 182.7 ± 8.2 cm; body mass 95 ± 10.7 kg) performed two jumps on the force platform separated by 3-5 minutes rest. When assessing between-day retest reliability, 13 rugby league players (age 19.3 ± 0.6 years; height 181.6 ± 5.4 cm; body mass 88.8 ± 9.8 kg) performed one jump on two occasions, 7 days apart. Both jumps were performed at the same time of day and followed 24 hours of inactivity leading up to a game. Prior to each jump, players performed a standardised warm-up involving dynamic stretches of the lower musculature followed by 2-3 submaximal jumps. Following the warm-up, players were instructed to keep their hands on hips for the entire jump, and to jump as high as possible. As reported previously, players received no instruction as to the depth of the countermovement performed prior to the concentric phase of the jump [30]. Peak power was the primary variable used in this thesis when assessing lower body muscle function.

3.2.2 Plyometric Push-up

A plyometric push-up (PP) on the same force platform as the CMJ was used to measure upper body muscle function. In order to determine the within-day retest reliability of the PP, 16 rugby league players (age 18.9 ± 0.6 years; height 182.3 ± 8.5 cm; body mass 93.7 ± 10.0 kg) performed two jumps on the force platform separated by 3-5 minutes rest. When assessing between-day retest reliability, 13 rugby league players (age 19.3 ± 0.6 years; height 181.6 ± 5.4 cm; body mass 88.8 ± 9.8 kg) performed one PP on two occasions, 7 days apart. Both PP were performed at the same time of day and followed 24 hours of inactivity leading up to a game. Prior to each PP, players performed a standardised warm-up involving dynamic stretches of the upper body musculature followed by 2-3 submaximal push-ups. For the PP, players were instructed to start in a push-up position with their hands on the force platform in a self-selected position, and arms extended. On the experimenter's signal, players were required to lower their body by flexing their elbows to a self-selected depth before extending the elbows as fast as possible so that their hands left the platform [30]. Peak power was the primary variable used in this thesis when assessing lower body muscle function.

3.3.3 Creatine Kinase

Blood creatine kinase (CK) was assessed as an indirect marker of muscle damage throughout the thesis. Eleven rugby league players (age 19.2 ± 0.4 years; height 182.3 ± 6.1 cm; body mass 86.9 ± 8.7 kg) provided two fingertip blood samples on separate fingers. Each blood sample was separated by 3-5 minutes. When assessing between-day retest reliability, the same 11 rugby league players provided two blood samples, 7 days apart. Both blood samples were collected at the same time of day and followed 24 hours of inactivity leading up to a game. After pre-warming of the hand, a 30 μl sample of blood was taken from a fingertip and analysed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, the instrument was calibrated in accordance with manufacturer recommendations.

3.3.4 Perceptual Wellbeing

Perceived wellbeing was assessed by the experimenter asking players to rate feelings of fatigue (very fresh, fresh, normal, more tired than normal, always tired); lower- and upper-body muscle soreness (great, good, normal, sore/tight, very sore); sleep quality (perfect, good, difficulty falling asleep, restless sleep, insomnia); mood (very positive, good, little interest in others, snappy at others, very annoyed); and stress (very relaxed, relaxed, normal, feeling stressed, very stressed) on 0-5 Likert scales, with the individual scores summated to give an overall wellbeing score. The retest reliability for the perceptual wellbeing questionnaire was determined by having 12 rugby league players (age 19.2 ± 0.5 years; height 182.5 ± 5.2 cm; body mass 89 ± 7.7 kg) complete the questionnaire on two occasions separated by 7 days following 36 hours of no physical activity.

3.3.5 Global Positioning System Microtechnology

The GPS units used in this thesis sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included a tri-axial accelerometer and gyroscope sampling at 100 Hz to provide information on collisions. Whilst the reliability and validity of these units was not examined in this thesis, there are numerous studies that have examined the reliability and validity of these GPS units. These studies have assessed the reliability and validity of these units during tasks that are commonplace in rugby league such as walking [160], sprinting [160-162], directional changes [163], and tackling [164].

3.4 Results

The reliability of each variable is expressed in Table 3.1. All of the variables show similar levels of within- and between-day reliability in the region of 3.0-3.9% with the exception of between-day blood CK which was 12.2%. Given the large magnitude of change in blood CK following rugby league match-play (often in the region of 200% increase and greater), this still clearly provides a reasonably sensitive measure for detecting any changes in blood CK. The other variables also show small TE values suggesting that they are sensitive for detecting changes in performance.

Table 3.1. The retest reliability of dependent variables. †

Measure	**Typical Error of Measurement (%)**	**Intraclass Correlation Coefficient (r)**
CMJ peak power within-day	3.9	0.918
CMJ peak power between-day	3.5	0.812
PP peak power within-day	3.1	0.969
PP peak power between-day	3.8	0.965
Blood CK within-day	3.3	0.995
Blood CK between-day	12.2	0.864
Perceptual wellbeing between-day	3.0	0.953

† CMJ = countermovement jump; PP = plyometric push-up; CK = creatine kinase

The reliability of the MinimaxX S4 units for sprinting and walking are reported in Table 3.2 below. All of these studies suggest that these units have good to moderate reliability at assessing sprinting over a range of distances in a linear direction. It is important to note that the reliability of these units is likely reduced when short, accelerative, multi-directional movements are performed that are commonplace in rugby league match-play [165]. In addition, these units can reliably detect collisions which is a vital aspect of rugby league training and competition that needs to be quantified. With regards the accuracy of these units, as the intensity of the movement increases and the distance decreases, so too does the validity of the measurement [163]. Despite this, there is no significant difference from criterion measures when assessing short, multi-directional accelerative sprints, over distances as small as 2 m [163]. Albeit small, these units do consistently underestimate true distances covered compared with criterion values. Practitioners should be mindful of this when analysing the results from GPS units. In addition to monitoring movements via GPS, the units also house an accelerometer sampling at 100 Hz to provide information on collisions and PlayerLoad (the square root of the sum of accelerations in each plane of movement) [166]. One study by Gabbett et al., [164] determined the validity of MinimaxX units for detecting the number of collisions in which players were involved. They reported no significant difference in the number of mild, moderate, and heavy collisions detected from the MinimaxX units and video recordings. Furthermore a correlation of r = 0.96 was reported between the MinimaxX detection of collisions and those from video recordings. As such, the units used in this study appear valid for quantifying the contact demands of training and competition. The same intensity bands used by Gabbett et al., [10] assigned to mild, moderate, and heavy collisions was used in this thesis. As well as monitoring collisions, MinimaxX units can provide a global measure of training load, termed "PlayerLoad". Boyd et al., [166] reported high levels of reliability for within- (TE = 0.91 to 1.05%) and between-devices (TE = 1.02 to 1.04%) in a laboratory setting as well as a TE of 1.9% in a field setting. As such, PlayerLoad appears to provide a reliable global measure of training load that differentiates between playing standard and position [167].

Table 3.2. Reliability and validity of MinimaxX S4 10 Hz GPS units for quantifying movements. †

Study	Movement	Distance	TE	Bias	SEE
Varley et al. [160]	Sprinting	< 100 m	2%	-0.2%	N/A
Varley et al. [160]	Walking	< 100 m	5.3%	0.6%	N/A
Castellano et al. [161]	Sprinting	15 m	1.5%	N/A	N/A
		30 m	1.0%		
Pyne et al. [162]	Sprinting	10-40 m	3.8-11.7%	N/A	6.2-13.9%

† TE = Typical error of measurement; SEE = Standard error of the estimate

3.5 Conclusions

The dependent variables used in this thesis offer good reproducibility making them sensitive for detecting changes in performance. In addition, the GPS units offer suitable reliability and accuracy for monitoring activity profiles in rugby league training and competition, despite a likely underestimation of distances covered. The accuracy of these units appears to increase as sprinting distance increases. It is also important to note, that in each study of this thesis, broad speed zones were used to classify movements, in an attempt to minimise the limitations associated with GPS technology.

Chapter 4

Theme 1 – Factors influencing pacing strategies in rugby league players

4.1 Study 1: Influence of physical contact on pacing strategies during small-sided games

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on pacing strategies during game-based activities. *Int J Sports Physiol Perform*, 2014, 9: 811-6.

4.1.1 Abstract

Repeated-sprinting incorporating tackles leads to greater reductions in sprint performance compared with repeated-sprinting alone. However, the influence of physical contact on the running demands of small-sided games is unknown. The aim of this study was to determine whether the addition of physical contact altered pacing strategies during small-sided games. A counter-balanced, cross-over experimental design was used. Twenty-three elite youth rugby league players were divided into two groups. Group 1 played the contact game on day 1 whilst group 2 played the non-contact game; 72 hours later they played the alternate game. Each game consisted of off-side touch on a 30 m x 70 m field, played over two 8 min halves. Rules were identical between games except the contact game included a 10 s wrestle bout every 50 s. Microtechnology devices were used to analyse player movements. There were greater average reductions during the contact game for distance (25%, 38 $m \cdot min^{-1}$ vs. 10%, 20 $m \cdot min^{-1}$; ES = 1.78 ± 1.02) and low-speed distance (21%, 24 $m \cdot min^{-1}$ vs. 0%, 2 $m \cdot s^{-1}$; ES = 1.38 ± 1.02) compared with the non-contact game. There were similar reductions in high-speed running (41%, 18 $m \cdot min^{-1}$ vs. 45%, 15 $m \cdot min^{-1}$; ES = 0.15 ± 0.95). The addition of contact to small-sided games causes players to reduce low-speed activity in an attempt to maintain high-intensity activities. Despite this, players were unable to maintain high-speed running whilst performing contact efforts. Improving a player's ability to perform contact efforts, whilst maintaining running performance should be a focus in rugby league players.

4.1.2 Introduction

Rugby league is a contact sport with periods of high- and low-intensity activity [2, 8]. During competition, players typically cover distances of 90-100 $m^{\cdot}min^{-1}$[2, 5, 8], including 6-14 $m^{\cdot}min^{-1}$ at high-speeds [2, 8]. In addition, to these running demands, players frequently engage in physical contact (i.e. tackles or hit-ups) during attack and defence. Gabbett et al., [10] reported that players performed 24-47 contact efforts during a game at a frequency of 0.38-1.09 per min depending on playing position. Furthermore, the frequency of physical contact is twice as high in defence than attack [5].

These contact efforts are a particularly demanding aspect of competition. Previous research has found that repeated-sprinting incorporating tackles is associated with greater peak (177 ± 8 $b^{\cdot}min^{-1}$ vs. 166 ± 9 $b^{\cdot}min^{-1}$) and average (169 ± 8 $b^{\cdot}min^{-1}$ vs. 154 ± 10 $b^{\cdot}min^{-1}$) heart rates and perceived exertion (12 ± 1 vs. 16 ± 1) than repeated-sprinting alone [9]. Moreover, post-match markers of muscle damage and neuromuscular fatigue are greater with a higher frequency of physical contact [27]. Johnston et al., [47] found that small-sided games involving physical contact were associated with greater increases in upper-body neuromuscular fatigue, blood creatine kinase (indicative of muscle damage) and perceived exertion, along with greater reductions in perceived wellbeing, despite lower running loads than non-contact games. Collectively, these data highlight the considerable physiological load and psychological stress associated with performing contact efforts.

Contact efforts during rugby league match-play normally precede or immediately follow high-intensity running [11]. Indeed, players will regularly perform high-intensity running efforts in combination with contact efforts with minimal rest between each effort. Such activity bouts have been defined as repeated high-intensity effort (RHIE) bouts [76]. These RHIE bouts that include tackles and running efforts are thought to be vital to the outcome of a match, with 70% of tries scored or conceded within 5 min of a RHIE bout [76]. Furthermore, winning teams perform more RHIE bouts per match, and more efforts per bout than losing teams [55]. As such, the ability (or inability) to repeatedly perform contact efforts while maintaining running performance may be critical to the outcome of a game [58]. Although RHIE performance discriminates between successful and less successful teams, it has also been shown that winning teams maintain a higher overall playing intensity, covering greater relative distance than losing teams [55]. With this in mind, it appears important that players are able to maintain running performance whilst performing contact efforts.

Pacing has been described as the efficient use of energy resources during exercise so that all available energy is utilised without compromising performance before the cessation of the event [168]. On the other hand, fatigue has been defined as sensations of tiredness and associated decrements in muscular performance and function [169]. While it is well documented that athletes from individual sports adopt pacing strategies in order to manage fatigue [170], recent evidence has shown that different pacing strategies might be adopted in high-intensity, intermittent team sports [16-18]. Research has suggested that during match-play, players adopt pacing strategies that reduce low-speed activity in order to maintain the high-intensity running demands of competition [17, 18]. Furthermore, rugby league players employ a pacing strategy that allows them to adequately complete game tasks, yet remain in a reasonable state following the contest [16]. It is thought that players pace in order to prevent failure of a single physiological system, and maintain homeostasis [13, 170]. Although speculative, it is proposed that these pacing strategies are regulated both consciously and subconsciously. The initial pacing strategy employed is set subconsciously, based on previous knowledge of the impending activity [170]. Throughout exercise, sensory information is delivered to the brain from the muscles and cardiovascular system. The brain interprets this information against expected outcomes and perceived exertion and makes a conscious decision to either increase or decrease exercise intensity [170]. Despite this, little is known regarding the effect that physical contact has on the running demands of match-play, and whether contact results in a different pacing strategy. Whilst it is impossible to eliminate contact from match-play, this can be done using small-sided games that have a similar stochastic nature to match-play [171]. It is important to determine the effect of physical contact on movement demands, as running performance is central to the outcome of a match [55].

Given the physiological and psychological stress associated with contact efforts [9, 47], it is plausible that the addition of such efforts to performance may alter the movement patterns and, in turn, the pacing strategies employed. Understanding the relationship between physical contact and locomotor activities may allow coaching staff to develop training drills to better prepare players to perform and tolerate the contact and running demands of competition. With this in mind, the aim of this study was to determine the influence of physical contact on running performance during small-sided games. It was hypothesised that the addition of contact to a small-sided game would cause greater reductions in low-speed running performance compared to a non-contact game so that players could maintain the high-speed running and contact components of the activity.

4.1.3 Methods

4.1.3.1 Design

In order to test our hypothesis, a counter-balanced, cross-over experimental design was used. Elite youth rugby league players participated in contact and non-contact small-sided games. Global positioning system (GPS) microtechnology devices were used to assess movements during the small-sided games. Players were randomly divided into two groups; one group played the small-sided game with no contact first followed by the small-sided game with contact 72 hours later; the second group played the games in reverse order.

4.1.3.2 Subjects

Twenty-three elite youth rugby league players (age 19.1 ± 0.8 years; height 178.3 ± 22.9 cm; body mass 93.7 ± 9.2 kg) from the same National Youth Competition (U20) team participated in the study. Data were collected in the penultimate week of pre-season, with players free from injury. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), players received an information sheet outlining experimental procedures; written informed consent was obtained from each player. Over the course of the testing period, players were asked to maintain their normal diet. The study was approved by the University's ethical review board for human research.

4.1.3.3 Small-Sided Games

Two small-sided games were performed in two training sessions, separated by 72 hours. Both games were 'off-side' small-sided games, one with contact, and one without contact, regularly used by the coaches during training. Players were divided into 4 teams of 6 players (one player was not fitted with a GPS unit), so there was an even spread of playing positions amongst each team. Teams 1 and 2 played the non-contact game first and then the contact game 72 hours later; teams 3 and 4 played the games in reverse order. Each game consisted of two 8 min halves separated by a 90 s rest interval played on a grass training pitch in a standardised (30 m x 70 m) playing area. The 'off-side' game permitted each team to have three 'plays' while in possession of the ball. A 'play' ended when the player in possession of the ball was touched by a defender with two hands. The ball was turned over when the attacking side had completed three 'plays', or if an error was committed. Unlike a regular small-sided rugby game, during the 'off-side' game, the ball was able to be passed in any direction (i.e. to 'off-side' players). The only difference between the two games was the addition of 8, 10 s contact and wrestle periods every 50 s during each half of the contact game. The players were asked to perform alternate shoulder pummels for 5 s, before being given 5 s to wrestle their partner onto their back. All players received coaching on wrestling techniques as part of their training and were familiar with this contact drill. Simulated contacts similar to those used in the present study have been shown to have good reproducibility in rugby league players [9]. After each contact period, the game resumed. Due to the 10 s contact period within each minute of the contact game, the ball was only in play for 50 s of each minute compared to the full 60 s of each minute in the non-contact game. In order to control for this difference, and allow direct comparisons between the two games, the 50 s of activity whilst the ball was in play during each minute of the contact game was extrapolated to 60 s. Other than the 16 contact periods, there was no difference in the rules, verbal encouragement, pitch size, player number, and match duration between the contact and non-contact game. In addition, 30 min after each game, rating of perceived exertion (RPE) was recorded using a CR-10 RPE scale to obtain an indication of how hard players perceived each game [172].

4.1.3.4 Global Positioning System Analysis

Game movements were assessed by GPS microtechnology devices fitted between the shoulder blades in a manufacturer-provided vest. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included 100 Hz tri-axial accelerometers, gyroscopes, and magnetometers to provide information on collisions and 2D Player Load™. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and subsequently analysed (Sprint, Version 5, Catapult Sports, VIC, Australia). Data were categorised into low-speed activity (0-5 $m \cdot s^{-1}$), and high-speed running (≥5.1 $m \cdot s^{-1}$).[2] Repeated high-intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration (≥2.78 $m \cdot s^{-2}$), high-speed, or contact efforts with less than 21 s between each effort [2]. The data were divided into 1-min blocks for analysis (16 in total) in order to determine the changes in running performance during each game. Player Load™ (2D) excludes the vertical accelerometer information and is therefore indicative of the load associated with the non-running components (i.e. physical contact) of the two games. Both the accelerometer and GPS technology housed within the units offer a valid and reliable method of quantifying movements that are commonplace in rugby league [160, 164, 173].

4.1.3.5 Statistical Analysis

The differences in movement demands between the contact and non-contact games and changes over each minute of each game were determined using traditional null hypothesis significance testing, and magnitude based inferences. A two-way (game x time) repeated measures ANOVA was performed using SPSS version 19 (SPSS for Windows, IBM Software, NY, USA) to determine the statistical significance of any main effects. Based on the real-world relevance of the results, magnitude based inferences were used to determine the practical meaningfulness of any differences. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x the between subject standard deviation. Thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; >99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]; ES of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± 95% confidence intervals (CI); the significance level was set at $p<0.05$.

4.1.4 Results

The absolute running loads of each game are presented in Table 4.1. During the non-contact game, players covered greater relative distance (ES = 0.45; Likelihood = 87%, Likely; p = 0.076) predominantly through greater distances covered at low speeds (ES = 0.50, Likelihood = 75%, Likely; p = 0.177) compared with the contact game. Only small differences (ES = 0.24, Likelihood = 56%, Possibly; p = 0.417) were found between the contact and non-contact games for the distance covered in high-speed running. There was a large, significantly greater 2D Player Load™ during the contact game compared to the non-contact game (ES = 2.69, Likelihood = 100%, Almost Certain; p = 0.001).

There were reductions in total distance during each min of the contact and non-contact small-sided games (Table 4.1A) with a significant main effect of game (p = 0.001) and time (p = 0.001), as well as a group by time interaction (p = 0.001). Moreover, the larger reductions in relative distance during the contact game compared with the non-contact game were practically meaningful (ES = 1.78; Likelihood = 100%, Almost Certain), with large reductions at each min after the first min of the contact game (ES = -1.23 to -3.66). During the non-contact game, there was only large reductions in relative distance during the 6^{th} (ES = -1.21), 13^{th} (ES = -1.53) and 14^{th} (ES = -1.34) min. The average reduction in relative distance compared to min 1 was 25 ± 4% and 10 ± 3% following the contact and non-contact games, respectively (Table 4.2).

Table 4.1. Running loads of the contact and non-contact small-sided games. †

	Contact	Non-Contact	Difference (%)	ES	Likelihood	Descriptor
Distance (m)	2191 (2126-2257)	2240 (2160-2319)	2.2 (1.6-2.7)	0.27	59/35/6%	Possibly
Relative Distance ($m \cdot min^{-1}$)	134 (129-138)	139 (134-144)	3.7 (3.1-4.3)	0.45	87/13/1%	Likely
High-speed running (m)	268 (235-301)	283 (242-324)	5.6 (3.0-7.6)	0.24	45/43/11%	Possibly
High-speed running ($m \cdot min^{-1}$)	16 (13-20)	17 (15-20)	6.3 (3-9.3)	0.24	56/37/7%	Possibly
Low-speed activity (m)	1905 (1837-1974)	1936 (1862-2009)	1.6 (1.3-1.9)	0.50	72/1/27%	Possibly
Low-speed activity ($m \cdot min^{-1}$)	115 (110-120)	120 (124-116)	4.3 (3.3-5.3)	0.50	75/23/2%	Likely
RHIE Bouts (no.)	1.0 (0.5-1.5)	0.3 (0.1-0.5)	70.0 (60-80)	0.36	0/73/26%	Possibly Not
2D Player Load (AU)	0.20 (0.19-0.21)	0.11 (0.11-0.12)	73.3 (71.0-74.6)	2.69	0/0/100%	Almost Certain

† Data are means and 95% confidence intervals. Difference (%) refers to the percentage difference between contact and non-contact games; likelihood refers to chances of difference being positive/trivial/negative.

Table 4.2. Average reduction in running loads from the first minute across the contact and non-contact small-sided games. †

	Contact	Non-Contact	ES	Likelihood	Descriptor
Distance (%)	25 (21-29)	10 (7-13)	1.78	100/0/0%	Almost Certain
High-speed running (%)	41 (31-51)	45 (34-54)	0.15	30/8/61%	Possibly Not
Low-speed activity (%)	21 (17-24)	0 (-4-3)	2.38	100/0/0%	Almost Certain

† Data are reported as means ± 95% confidence intervals. Low-speed activity refers to movements ≤5 $m \cdot s^{-1}$; high-speed running refers to movements ≥5.1 $m \cdot s^{-1}$. ES = Effect size difference; effect sizes of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate, and large, respectively. Likelihood refers to chances of difference being positive/trivial/negative: descriptor refers to the chance that the difference between the contact and non-contact games is practically meaningful.

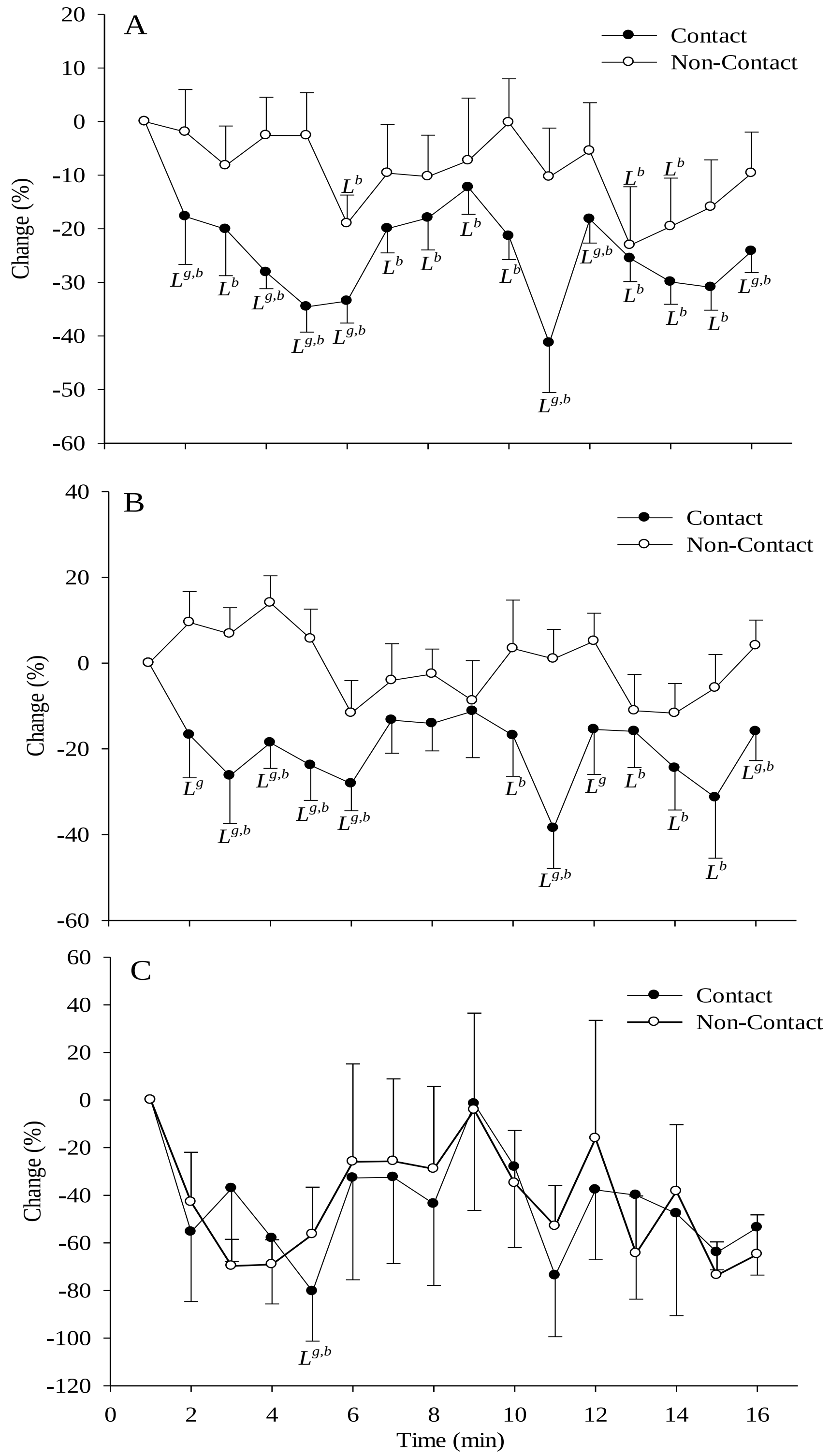

Figure 4.1. Changes in (A) overall meters per minute, (B) low-speed meters per minute (0–5 m.s-1), and (C) high-speed meters per minute (≥5.1 m.s-1) during the contact and noncontact small-sided games, mean ± 95% confidence intervals. *L* Denotes a large effect size difference (≥1.20) from baseline (L^b) and between games (L^g).

There were no reductions in low-speed activity during the non-contact game, but marked reductions during the contact game (Table 4.1B), with a significant main effect of game (p = 0.001) and time (p = 0.001), as well as a game by time interaction (p = 0.001). During each min of the contact game, there was an average reduction of 21 ± 3% in low-speed activity, whereas the average change in the non-contact game was 0 ± 3% (ES = 2.38; Likelihood = 100%, Almost Certain). Furthermore, there were large ES differences between the contact and non-contact games in the 2^{nd}-6^{th} and 11^{th}, 12^{th} and 16^{th} min (ES = 1.20-2.86).

There were similar reductions in high-speed running during the contact and non-contact games (Table 4.1C). There was a significant main effect of time (p = 0.001). However, no significant differences were found between games (p = 0.735; ES = 0.15; Likelihood = Possibly Not), nor were there significant condition by time interactions (p = 0.781). There was an average reduction in high-speed running of 41 ± 10% in the contact game, and 45 ± 9% in the non-contact game (Table 4.2).

Whilst there was significantly greater 2D Player Load™ during the contact game compared with the non-contact game (p = 0.001), there was no main effect of time on 2D Player Load™ during both games (p = 0.796; ES = -0.30; Likelihood = Trivial)

There was a small, significant difference in the RPE for each game, with a mean of 6.9 ± 0.4 for the contact game and 6.3 ± 0.6 for the non-contact game (p = 0.05) although the likelihood of this difference being practically meaningful was unlikely (Likelihood = Unlikely, 8%; ES = 0.41 ± 0.85).

4.1.5 Discussion

This study investigated the effect of physical contact on the pacing strategies employed by rugby league players during small-sided games. Our hypothesis was confirmed, with greater reductions in total distance and low-speed activity during the contact small-sided game compared with the non-contact small-sided game. There were large reductions in high-speed running, which were similar between the two games. The contact game was associated with greater 2D Player Load™ that was maintained throughout the game, suggesting players prioritised contact efforts over running performance. These findings suggest that players adopt different pacing strategies during small-sided games that incorporate physical contact, compared to activities that involve no contact. The addition of contact results in players reducing non-essential low-speed activity in an attempt to maintain intensity in the contact efforts.

Previous research suggests that players employ pacing strategies whereby they reduce non-essential low-speed activity in order to preserve high-speed running efforts [17, 18]. This was not the case in the present study, with no change in low-speed activity in the non-contact game. Whilst there were large reductions in low-speed activity in the contact game, it did not translate to the maintenance of high-speed running. However, players did maintain the intensity of contact efforts, highlighted by trivial changes in 2D Player Load™ throughout the game. Given the high relative intensity of the contact game (134 ± 17 m·min^{-1}) in comparison to match-play [58], it is likely that players were unable to maintain both running and contact performance. In team-sports with high running volumes, yet low contact volumes, players reduce the non-essential low-speed activity to maintain high-speed running [17, 18]. A potential reason that this did not occur in the present study could be that the players are aware that contact efforts are central to success in rugby league [25], and therefore prioritise these high-intensity contact efforts above running efforts. Despite this, the ability to recover at a high relative intensity is central to the outcome of a game [55]. As such, these findings could have potential implications for match performance. Low-speed activity appears important to the outcome of a match, with moderate (7-17 points) and large (≥18 points) winning margins associated with greater distances covered at low speeds. Therefore reductions in low-speed activity, as seen during the contact game, could compromise match performance. With this in mind, conditioning activities should attempt to improve players' ability to perform contact efforts without compromising running performance.

During both games there were similarly large reductions in high-speed running. These reductions occurred during the first few minutes of the first-half before returning to baseline by minute 8, indicative of a variable pacing strategy and transient fatigue [13, 85]. However, during the second-half, there were gradual reductions in high-speed running; with only small increases towards the end of the game, indicative of an 'end-spurt'. Despite this, the small magnitude of this 'end-spurt' indicates significant player fatigue [47, 177]. The first-half pacing strategy may have been employed to preserve energy for an end-spurt in the second-half. However, in the second-half, when players were in clear sight of the end-point, they utilised an all-out pacing strategy, similar to an interchange player [16]. It is likely that such a high running intensity (contact = 134 ±17 $m \cdot min^{-1}$; non-contact = 140 ± 5 $m \cdot min^{-1}$) in comparison to the intensity of match-play (95 ± 10 $m \cdot min^{-1}$) [58] was too high to maintain throughout the entire game, resulting in reductions in high-speed running performance [85]. Furthermore, the relatively short duration of the games was likely to result in players setting higher pacing strategies as observed in interchange players, compared with whole-match players [16]. The large reductions in high-speed running suggest that pacing strategies were employed that resulted in significant fatigue, resulting in the reduction of high-speed running.

There was a significantly greater perceived exertion associated with the contact game compared with the non-contact game. This is in line with previous research that has reported greater perceived exertion when performing repeated-effort exercise (tackles and sprints) compared to repeated-sprints in isolation [9]. These results are not surprising given the high-intensity nature of contact efforts [10, 47], which result in greater disturbances in homeostasis [9, 47]. This results in greater sensory feedback to the brain during exercise [170], resulting in subconscious increases in perceived exertion [178]. An elevated RPE above anticipated levels during exercise leads to reductions in power output, and consequently, exercise performance [179]. These data highlight the psychological stress associated with performing tackles and contact efforts. Clearly, players need to be mentally prepared to perform the frequent contact efforts that occur over the course of a game [2, 76].

4.1.6 Conclusions

These results suggest that the addition of contact to small-sided games causes players to reduce low-speed activity in an attempt to maintain high-intensity activities. Despite this pacing strategy, players are unable to maintain both high-speed running and contact efforts. As such, players prioritise the maintenance of contact efforts over high-speed running. In the non-contact game, fatigue was evident with the maintenance of low-speed activity but reductions in high-speed activity. Improving a player's ability to perform contact efforts, whilst maintaining running performance should be a focus of rugby league training programmes. There are some limitations associated with this study that warrant discussion. The sample size was relatively small, and given the inherent variability in the demands of small-sided games, further research should be conducted to ascertain the influence of contact on running performance. In addition, the assessment of heart rate data would have been useful. Although physical contact increases heart rate responses [9]. it would have been interesting to know how this changed throughout the two games. Future research should aim to determine the internal load associated with contact efforts, and the impact of these contact efforts on external load.

4.1.7 Practical Applications

- Targeting opposition players in attack, making them perform more tackles, could potentially lead to greater reductions in running performance.
- The inclusion of contact to small-sided games challenges a player's ability to maintain running performance. It is likely that improving the ability to perform running interspersed with contact efforts (repeated high-intensity effort ability) is beneficial to rugby league players, and should be central to conditioning programmes. Using contact and running efforts that replicate the most demanding passages of match-play is likely to allow players to better maintain running performance during a game.

4.1.8 Acknowledgments

The authors would like to thank the playing and coaching staff of the Melbourne Storm rugby league club for taking part in this study.

4.2 Study 2: Are three contact efforts really reflective of a repeated high-intensity effort bout?

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, Walker S, Walker B, and Jenkins DG. Are three contact efforts really reflective of a repeated high-intensity effort bout? *J Strength Cond Res*, 2015, 29: 816-821.

4.2.1 Abstract

The use of 3 or more efforts (running and contact), separated by short recovery periods, is widely used to define a 'repeated high-intensity effort' (RHIE) bout in rugby league. It has been suggested that due to fatigue, players become less effective following RHIE bouts; however, there is little evidence to support this. This study determined whether physical performance is reduced after performing 1, 2, or 3 efforts with minimal recovery. A counter-balanced, cross-over experimental design was used. Twelve semi-professional rugby league players (age 24.5 ± 2.9 years) competed in three 'off-side' small-sided games (2 x 10 min halves) with a contact bout performed every 2 min. The rules of each game were identical except for the number of contact efforts performed in each bout. Players performed 1, 2, or 3 x 5 s wrestling bouts in the single-, double- and triple-contact game, respectively. Movement demands of each game were monitored using global positioning system units. From the first to the second half, there were trivial reductions in relative distance during the single-contact game (ES = -0.13 ± 0.12), small reductions during the double-contact game (ES = -0.47 ± 0.24), and moderate reductions during the triple-contact game (ES = -0.74 ± 0.27). The present data show that running intensity is progressively reduced as the number of contact efforts per bout is increased. Targeting defensive players and forcing them to perform two or more consecutive contact efforts is likely to lead to greater reductions in running intensity. Conditioning performing multiple contact efforts whilst maintaining running intensity should therefore be incorporated into training for contact team sports.

4.2.2 Introduction

Rugby league is a collision sport characterised by periods of high- (e.g. sprinting, tackling, wrestling) and low-intensity (e.g. jogging, walking, standing) activity [2, 8]. During competition, players typically cover distances of 90-100 $m \cdot min^{-1}$ [2, 5, 8], including 6-14 $m \cdot min^{-1}$ at high-speeds [2, 8]. In addition to these running demands, players are also involved in frequent physical collisions involving blunt force trauma as well as wrestling and grappling efforts. Depending on position, players are involved in 24-47 contact efforts during a game at an average frequency of 0.38-1.09 per min [10]. However, players are often required to perform contact efforts at a much greater frequency during certain passages of play. Indeed, the frequency of physical contact is twice as high in defence compared with attack (1.9 ± 0.7 vs. 0.8 ± 0.3 per min) [25]. These collisions and contact efforts are associated with increased physiological and psychological loads [9], muscle damage [47, 27], upper body fatigue [47], and reductions in running performance [20]. As such, players are required to maintain a sufficient running intensity whilst regularly performing repeated contact efforts and high-intensity running actions.

Given the high physiological cost associated with performing contact efforts, coaches often use tactics that involve targeting a certain defensive player during a period of play, or over an entire game. This results in the player having to make multiple tackles in quick succession. It is believed that forcing a player to make 3 consecutive tackles, reduces their effectiveness during match-play for a certain length of time (9), most likely due to cumulative fatigue resulting from the repeated contact efforts [9]. Early research within the sport of field hockey aimed to quantify the most demanding passages of competition and defined repeated-sprint bouts as 3 or more sprints with less than 21 seconds between each sprint [81]. Whilst this may be adequate for non-contact sports, repeated-sprint bouts overlook the highly demanding contact efforts that are commonplace in rugby league [9], and therefore underestimate the worst-case demands of competition. As such, Austin and colleagues described repeated high-intensity effort (RHIE) bouts [76], which included repeated sprints, and also contact efforts. Specifically, a RHIE bout was defined as 3 or more contact or high-speed running efforts with less than 21 seconds between each effort (1). More recently, with the development of global positioning system (GPS) technology, maximal accelerations have been integrated into the

RHIE definition alongside contact and high-speed running efforts [2]. The evidence in support of 3 RHIE being important to physical performance outcomes is largely anecdotal (9) and only one study in rugby league has suggested this may be the case [9]. The authors noted that players could only maintain sprint performance for 3 efforts (2 sprints and 1 tackle), during a repeated-effort test, before sprint performance was markedly impaired [9]. However, only amateur players were examined in this study [9], and players did not perform back-to-back tackles. It may be that 2 back-to-back contact efforts are all that are required to impair performance, and render a player relatively ineffective. In addition, a recent study examining the RHIE demands of elite and semi-elite competition highlighted that the majority of RHIE bouts were comprised of 2 efforts, and semi-elite players performed a greater proportion of 2 effort bouts compared with their elite counterparts [65]. As such, it appears that performing 2 efforts within a RHIE bout poses considerable physical demands on players, which may impact on subsequent performance.

The aim of this study was to compare the influence of 1, 2, or 3 contact efforts in a single bout on running performance during small-sided games. It was hypothesised that as the number of contact efforts increased, so too would the reductions in running performance.

4.2.3 Methods

4.2.3.1 Design

A counter-balanced, cross-over experimental design was used to test our hypothesis. Players were randomly divided into three groups, and played each small-sided game in a counter-balanced fashion over a 10 day period separated by at least 72 hours. GPS microtechnology devices assessed movements during the small-sided games.

4.2.3.2 Subjects

Thirty-six semi-professional rugby league players from the same rugby league club participated in the study. Twelve of the 36 players (mean ± SD age 24.5 ± 2.9 years; body mass 90.4 ± 7.2 kg) wore GPS units during each game, and these 12 players provided the data for this study. All data were collected during weeks 4 and 5 of the pre-season period, with players free from injury. Over the course of the testing period, players were asked to maintain their normal diet. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), players received an information sheet outlining experimental procedures; written informed consent was obtained from each player. The study was approved by the University's ethical review board for human research.

4.2.3.3 Small-Sided Games with Contact

The three games were 'off-side' small-sided games, regularly used by rugby league coaches during training. Unlike a regular small-sided rugby game, during 'off-side' games, the ball can be passed in any direction (i.e. to 'off-side' players). Within each of the three groups, players were divided into two teams of 6 players, ensuring an even spread of playing positions. Each game consisted of two 10 min halves separated by a 2 min rest interval played on a grass training pitch in a standardised (30 m x 70 m) playing area. The 'off-side' game used the same rules as those reported previously (16) and each team was permitted to have three 'plays' while in possession of the ball. A 'play' ended when the player in possession of the ball was touched by a defender with two hands. The ball was turned over when the attacking side had completed three 'plays', or if an error was committed. Every 2 min of each game, players performed a contact bout (eight contact bouts in total), with players allowed 5 s to find a partner. The only difference between the three games was the number of contact efforts in each contact bout. In game 1, players performed a single contact effort each bout (8 in total); game 2 involved two contact efforts each bout (16 in total); game 3 involved 3 contact efforts each bout (24 in total). From a standing position, one step away from their partner, players were asked to perform a single shoulder contact, before being given 5 s to wrestle their partner onto their back. In games 2 and 3 when players performed multiple contacts, each 5 s contact was separated by 2 s of rest. All players received coaching on wrestling techniques as part of their training and were familiar with this contact drill. Similar simulated contacts have shown good reproducibility in rugby league players [9]. After each contact period, the game resumed. Other than the number of contact bouts, there was no difference in the rules, verbal encouragement, pitch size, player number, or match duration between games. Due to the varying length of each contact period (single-contact = 10 s [5s to find partner; 1 x 5 s wrestle]; double-contact = 17 s [5s to find partner; 2 x 5 s wrestle; 1 x 2 s rest]; triple-contact = 24 s [5s to find partner; 3 x 5 s wrestle; 2 x 2 s rest]) only active playing time (less the contact periods) was analysed; distances covered were expressed relative to ball in play time.

4.2.3.4 Time-Motion Analysis

The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included a 100 Hz tri-axial accelerometer and gyroscope to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and subsequently analysed (Sprint, Version 5.1.1, Catapult Sports, VIC, Australia). Data were categorised into low-speed activity (0-3.5 $m \cdot s^{-1}$), moderate-speed running (3.6-5.0 $m \cdot s^{-1}$) and high-speed running ($\geq$5.1 $m \cdot s^{-1}$) [2]. Data were divided into 5 min blocks for analysis in order to determine the changes in running performance during each game. Player Load™ Slow ($<$2 $m \cdot s^{-1}$) was used to determine the load associated with the non-running components (i.e. physical contact) of the games [167]. These units offer valid and reliable estimates of movements common in rugby league [160, 164].

4.2.3.5 Statistical Analyses

The practical meaningfulness of any differences in movement demands between the three games was determined using magnitude based inferences. The likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size (ES) of 0.20 x the between subject standard deviation; an ES of 0.20 was used as this is the smallest effect size that is deemed practically meaningful. Thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; ≥99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's ES statistic [175]. An ES of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± 95% confidence intervals (CI).

4.2.4 Results

The differences in playing intensities and distance covered in each speed zone are shown in Figure 4.2. During the first half of each game, there was no difference in relative distance (ES = -0.11 to 0.10), low-speed activity (ES = -0.38 to 0.35), moderate-speed running (ES = -0.20 to 0.24), and high-speed running distance (ES = -0.06 to 0.11) covered. Although not practically meaningful, Player Load™ Slow (Figure 4.3) was moderately higher in the first half of the triple-contact game compared with the single-contact game (ES = 0.98 ± 1.0; likelihood = possibly, 36%).

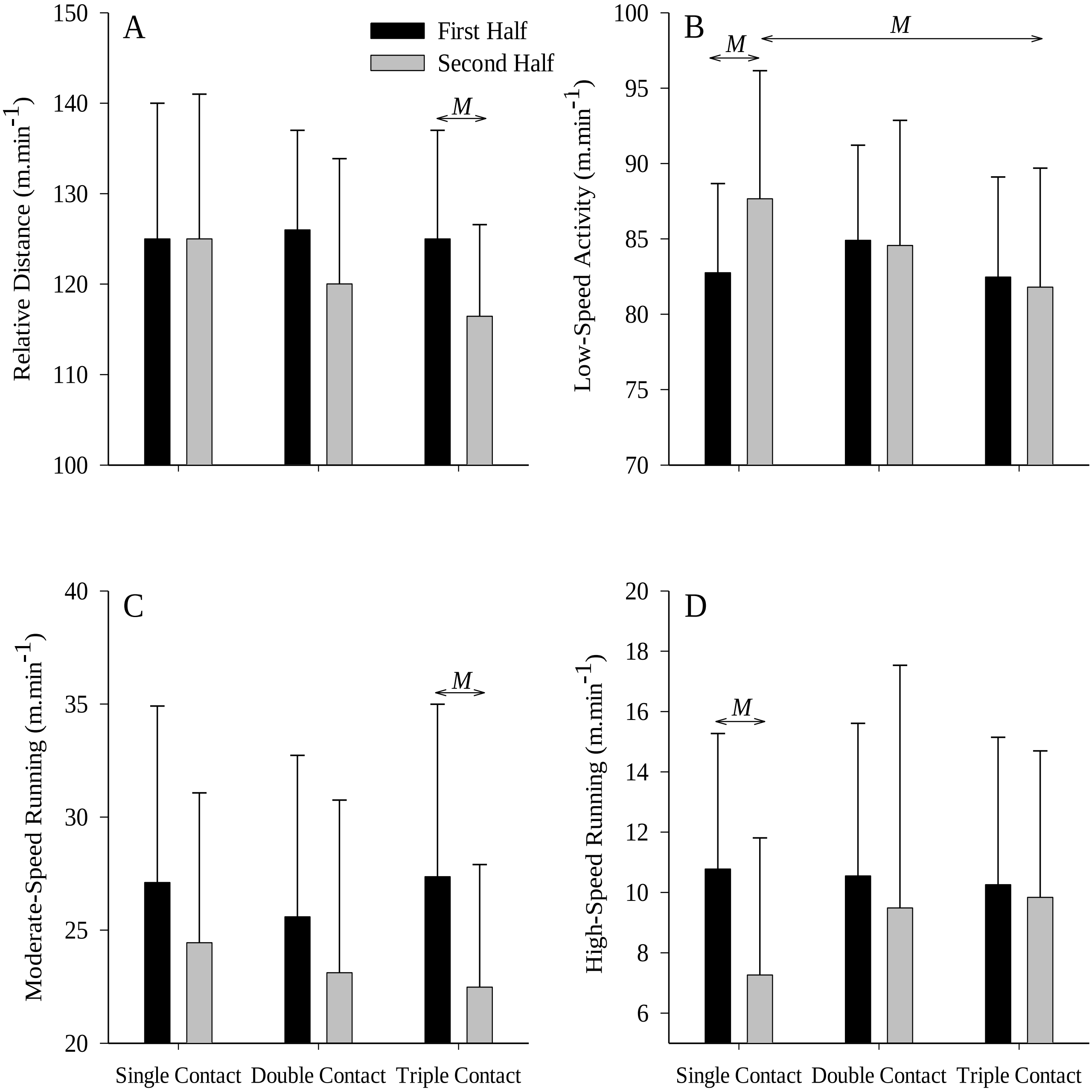

Figure 4.2. Relative distance (A), low-speed activity (0-3.5 m·s-1) (B), moderate-speed running (3.6-5.0 m·s-1) (C), and high-speed running (≥5.1 m·s-1) (D) during the first and second half of the single, double, and triple-contact games. *M* Denotes a moderate effect size difference (0.61-1.19). Data are presented as means ± SD.

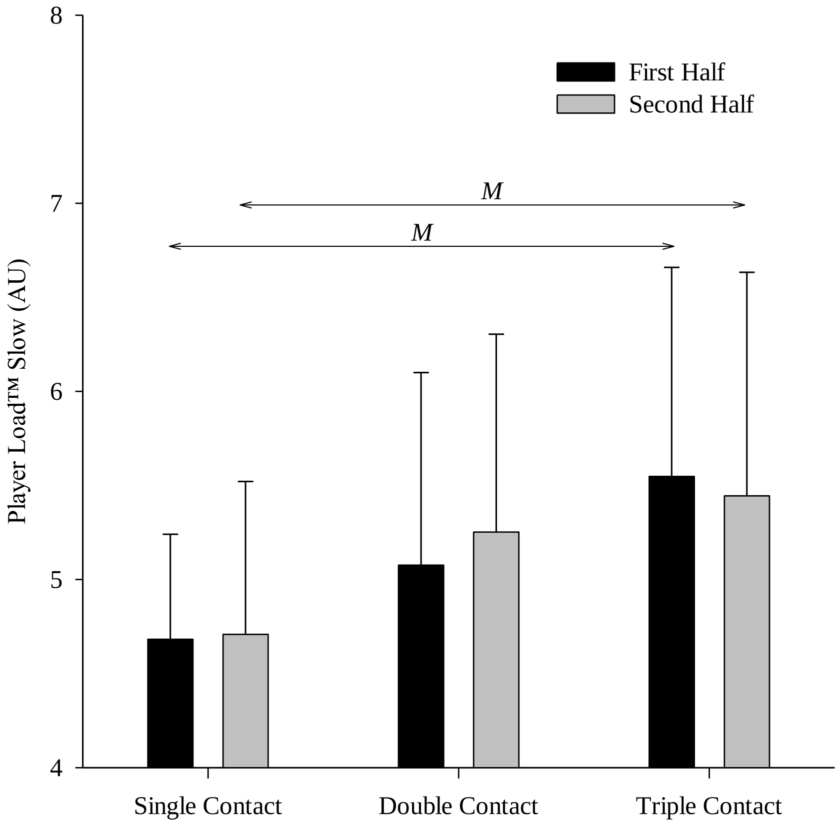

Figure 4.3. Player Load™ Slow during the first and second half of the single, double, and triple-contact games. *M* Denotes a moderate effect size difference (0.61-1.19). Data are presented as means ± SD.

During the second half of the game, the relative distance covered was lower in the triple-contact game compared with the single-contact game (ES = -0.40 ± 0.24; likelihood = likely, 78%); there was little difference between the single- and the double- (ES = -0.21 ± 0.13), or the double- and triple-contact game (ES = -0.17 ± 0.45). From the first to the second half, there was a trivial reduction in relative distance in the single-contact game (ES = -0.13 ± 0.12; likelihood = possible, 56%), a small reduction in the double-contact game (ES = -0.47 ± 0.24; likelihood = likely, 82%), and a moderate reduction in the triple-contact game (ES = -0.74 ± 0.27; likelihood = likely, 88%). There was a moderate increase in low-speed activity during the second half of the single-contact game (ES = 0.67 ± 0.17; likelihood = likely, 90%), and only trivial decreases in the double- (ES = -0.05 ± 0.14) and the triple-contact game (ES = -

0.09 ± 0.12). Low-speed distance during the second half of the single-contact game was moderately greater than during the triple-contact game (ES = 0.71 ± 0.38; likelihood = possibly, 73%). Whilst there were only small reductions in moderate-speed running in the second half of the single- (ES = -0.37 ± 0.21; likelihood = possibly, 71%) and double-contact games (ES = -0.33 ± 0.22; likelihood = possibly, 69%), there was a moderate reduction in the triple-contact game (ES = -0.74 ± 0.24; likelihood = likely, 92%). High-speed running was maintained between the first and second halves in the double- (ES = -0.16 ± 0.72; likelihood = possibly, 51%) and triple-contact games (ES = -0.09 ± 0.61; likelihood = possibly, 39%), but showed moderate reductions in the single-contact game (ES = -0.78 ± 0.32; likelihood = likely, 91%). Player Load™ Slow (Figure 4.3) was maintained in the second half of each of the three games (ES = -0.09 to 0.17). Consistent with the first half, Player Load™ Slow was greater in the second half of the triple-contact game, compared with the single-contact game (ES = 0.72 ± 0.38; likelihood = possibly, 27%).

4.2.5 Discussion

The results of this study confirmed our hypothesis and highlight that greater reductions in running intensity occur as the number of contact efforts performed in a single bout increase. In addition, it lends support to the classification of RHIE bouts requiring a minimum of 3 or more efforts. However, it is clear that running intensity reduces progressively as the number of contact efforts increases. It is likely that performing more contact efforts will lead to larger, longer lasting reductions in running performance. Players need to be conditioned appropriately to minimise reductions in running performance whilst affecting multiple contact efforts in quick succession.

In the single-contact game, playing intensity was maintained from the first to the second half, whereas there were small reductions in the double-contact game and moderate reductions in the triple-contact game. These results highlight that when players are required to perform multiple contact efforts in quick succession, reductions in running performance do occur. Although there were small reductions in the double-contact game, the larger reductions observed in the triple-contact game highlight the cost of performing multiple contact efforts.

As such, targeting defensive players in attack is likely to be advantageous and could influence match-play in a number of ways. Firstly, fatigue following RHIE exercise causes reductions in tackling technique in rugby league players [84], which in turn can lead to more missed and fewer dominant tackles during match-play [141], potentially increasing the number of points conceded. Secondly, increased fatigue following high-intensity passages of play results in decreases in the number of involvements with the ball and a reduction in the quality of skill execution in the subsequent 5 min period [77]. This could have important ramifications if the player who has made numerous consecutive tackles is in a key ball playing position (e.g. half or hooker). With this in mind, at certain times during match-play, coaches may benefit from targeting individual defensive players, forcing them to perform 3 or more consecutive tackles, in order to promote defensive errors and minimise their involvement in any subsequent attack.

The definition of a RHIE bout originated from the sport of field hockey [81], and has since been used in rugby league [4, 58, 76]. Despite this, it is unclear whether the use of 3 efforts is indeed valid when defining a RHIE bout in rugby league. It could well be, that a bout involving 2 efforts still reflects a demanding passage of play and results in significant fatigue [19]. The present data are in accordance with those of others [9], whereby performing 3 high-intensity efforts in close proximity to one another leads to reductions in running performance. Whilst players can maintain overall running intensity when performing single contact efforts in a bout, performing double contact efforts results in small reductions in running performance. Previously, research has only focused on RHIE bouts that include 3 or more efforts, with players performing in the region of 8-10 bouts over the course of a game [4, 58, 76]. However, recently it was shown that players perform numerous bouts involving 2 efforts that are physically demanding [65], yet these efforts are not recognised as RHIE bouts in rugby league [19]. Moreover, there are greater reductions in the frequency of RHIE bouts involving contact between the first and second halves compared with non-contact RHIE bouts [65], further highlighting the physical performance reductions associated with performing repeated-contact efforts. With this in mind, coaches should condition players so that they are capable of performing RHIE bouts with varying numbers of efforts, durations, and activities. Moreover, it is vital players are physically prepared to perform repeated-contact efforts.

Although there was a greater reduction in overall running intensity as the number of contact efforts increased, there was a difference in the way players either reduced or maintained match intensity between games. In the single-contact game, there was no reduction in overall intensity and this was achieved by increasing low-speed activity whilst there were small and moderate reductions in moderate- and high-speed running, respectively. In the double- and triple-contact games, the reductions in running intensity were primarily brought about through reductions in moderate-speed running, with only small reductions in low-speed activity and high-speed running. Due to the high contact and RHIE demands of rugby league competition (9), and relatively lower running intensities than those of the current games [2], it is possible that players were unaccustomed to the large running component of the single-contact game. As such, players were unable to maintain the initial intensity and reduced high-speed running distance. The increases in low-speed activity in the second half of the single-contact game could reflect players relying on passes to move the ball, rather than running efforts. Unfortunately, the number of skill involvements was not assessed in the present study. The similar activity profiles in the double- and triple-contact games are not surprising given the repeated contact nature of these two games. The reduction in moderate-speed running and maintenance of high-speed running and Player Load™ Slow are indicative of a pacing strategy whereby players reduce non-essential activities so that the essential high-intensity movements can be maintained [20]. Based on this information, it appears that players modify their activity depending on the proportion of contact and running performed. As such, players need to be exposed to the appropriate contact and running demands of competition to obtain sufficient conditioning and allow them to set appropriate pacing strategies during match-play.

4.2.6 Conclusions

This study highlights that increasing the number of contacts in a single bout leads to greater reductions in running intensity which influences the pacing strategy adopted by players. While the findings lend support to the use of 3 efforts to define a RHIE bout, small reductions in running intensity also occur when players are required to perform double contact efforts. Future research should aim to compare the influence of 2, 3, and 4 efforts on both running performance and skill outcomes between different playing standards. In addition, this study only assessed the influence of repeated contact efforts. Future research should investigate the influence high-intensity running efforts and a combination of running and contact efforts have on subsequent game intensity. A limitation of the present study was the use of 'off-side' games as opposed to the 'on-side' nature of rugby league match-play. Future research should assess the influence of RHIE bouts on running performance during 'on-side' games. In addition, due to the stochastic nature of the games, players may have performed high-intensity running efforts immediately preceding or following the contact bouts which may have led to further decrements in running performance.

4.2.7 Practical Applications

- Targeting players in attack, forcing them to perform two or more consecutive contact efforts is likely to lead to greater reductions in running intensity and potentially tackling technique and skill involvements.
- Although the greatest reductions in running intensity occurred during the triple-contact game, players still need to be prepared for the various contact and running demands of competition.
- Double effort RHIE bouts are physically demanding for players and such bouts should be incorporated into conditioning drills.

4.2.8 Acknowledgments

The authors would like to thank the players and staff of the Ipswich Jets Rugby League Club for volunteering to participate in the study. No sources of funding were used to carry out this research.

4.3 Study 3: Influence of the number of contact efforts on running performance during small-sided games

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of the number of contact efforts on running performance during game-based activities. *Int J Sports Physiol Perform*, 2015, 10: 740-745.

4.3.1 Abstract

To determine the influence the number of contact efforts during a single bout has on running intensity during small-sided games and assess relationships between physical qualities and distances covered in each game. A within-subject, counter-balanced repeated-measures experimental design was used. Eighteen semi-professional rugby league players (age 23.6 ± 2.8 years) competed in three 'off-side' small-sided games (2 x 10 min halves) with a contact bout performed every 2 min. The rules of each game were identical except for the number of contact efforts performed in each bout. Players performed 1, 2, or 3 x 5 s wrestles in the single-, double- and triple-contact game, respectively. The movement demands (including distance covered and intensity of exercise) in each game were monitored using global positioning system units. Bench press and back squat 1 repetition maximum and 30-15 intermittent fitness test (30-15IFT) assessed muscular strength and high-intensity running ability, respectively. There was little change in distance covered during the single-contact game (ES = -0.16 to -0.61) whereas there were larger reductions in the double- (ES = -0.52 to -0.81) and triple-contact (ES = -0.50 to -1.15) games. Significant relationships ($p<0.05$) were observed between 30-15IFT and high-speed running during the single ($r = 0.72$) and double- ($r = 0.75$), but not triple-contact ($r = 0.20$) game. There is little change in running intensity when only single-contacts are performed each bout; however when multiple contacts are performed, greater reductions in running intensity result. In addition, high-intensity running ability is only associated with running performance when contact demands are low.

4.3.2 Introduction

Rugby league is a contact sport with periods of high- (e.g. sprinting, collisions, wrestling) and low-intensity (e.g. jogging, walking, standing) activity [2, 8]. During competition, players typically cover distances of 90-100 $m \cdot min^{-1}$[2, 5, 8], including 6-14 $m \cdot min^{-1}$ at high-speeds (>3.9 $m \cdot s^{-1}$) [2, 8]. Winning teams cover greater relative distances than losing teams [55], and higher ranked junior teams cover greater relative high-speed distance than lower ranked teams [60]. In addition, players with superior high-intensity running ability are more likely to be selected into a semi-professional rugby league team, and perform more high-speed running during match-play [24]. As such, the ability to maintain high-speed running over the course of a game appears to be a key factor associated with successful teams and players.

In addition to these running demands, players frequently engage in physical contact (i.e. tackles, hit-ups, and wrestles) during attack and defence [5]. Gabbett et al., [10] reported that players performed 24-47 contact efforts during a game at a frequency of 0.38-1.09 per min depending on playing position. Despite this, players often perform contact efforts at a much greater frequency during certain passages of play. Indeed, the frequency of physical contact is twice as high in defence compared with attack (1.9 ± 0.7 vs. 0.8 ± 0.3 per min) [25]. Performing a number of physical collisions in close proximity to one another significantly increases the physiological demands imposed on players [9, 47]. Contact efforts may occur within repeated high-intensity effort (RHIE) bouts [25]. These RHIE bouts tend to occur at important times during a game; the greatest frequency of RHIE bouts occur when defending the try-line [25], and 70% occur within 5 min of a try being scored [76]. Moreover, winning teams perform more RHIE bouts during match-play, and more efforts within each bout [55].

The available evidence suggests that to be successful, rugby league players require a high capacity to engage in repeated contacts (often in close proximity to one another) whilst maintaining a high running intensity. Although high-intensity running ability is linked to high-speed distance covered during games, it is not associated with RHIE ability [24]. This suggests that the large contact component associated with RHIE bouts [76] requires aspects of fitness that are independent of high-intensity intermittent running ability. Despite this, it is unclear at what point the dissociation occurs between high-intensity running ability and RHIE performance. Previous research has shown that performing single-contact efforts intermittently with repeated sprints results in greater reductions in running performance compared to performing running efforts alone [9]. However, it is unclear what effect multiple contact efforts have on movements during small-sided games, as well as the influence multiple contacts have on running performance.

With this in mind, the aim of the present study was to examine the influence of performing one, two, or three contact efforts in a single bout on movement patterns during small-sided games. In addition, the relationships between strength and high-intensity running ability and game movements were assessed. It was hypothesised that (1) as the number of contact efforts increased, so too would the reductions in high-speed running and (2) the relationship between high-intensity running ability and distances covered would decrease as the number of contact efforts increased.

4.3.3 Methods

4.3.3.1 Design

In order to test our hypothesis, a counter-balanced, cross-over experimental design was used. Prior to participating in three small-sided games, high-intensity intermittent running ability, muscular strength and power were assessed in rugby league players. Global positioning system (GPS) microtechnology devices were used to assess movements during the small-sided games. Players were randomly divided into three groups, and played each small-sided game in a counter-balanced fashion over a 10 day period separated by at least 72 hours.

4.3.3.2 Subjects

Eighteen semi-professional rugby league players (age 23.6 ± 2.8 years; body mass 91.2 ± 8.8 kg) from the same rugby league club participated in this study. Data were collected during weeks 6 and 7 of the pre-season period, with players free from injury. Over the course of the testing period, players were asked to maintain their normal diet. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), players received an information sheet outlining experimental procedures; written informed consent was obtained from each player. The study was approved by the University's ethical review board for human research.

4.3.3.3 Protocol

Five and seven days prior to the first small-sided game, players completed tests to determine muscular strength and high-intensity intermittent running ability. Each test was performed at the start of a separate training session, separated by 72 hours. The 30-15 Intermittent Fitness Test (30-15IFT) was used to assess high-intensity intermittent running ability [180]. Following habituation, players performed the test on a grass playing surface with players wearing training clothes and football boots; the protocol and sensitivity of the 30-15IFT has been described previously [180, 181]. Upper- and lower-body muscular strength was assessed using a 1 repetition maximum (1RM) bench press and back squat, respectively, using the same procedures outlined by Baker and Nance [122].

4.3.3.4 Small-Sided Games with Contact

The three games were 'off-side' small-sided games, regularly used by rugby league coaches during training. Unlike a regular small-sided rugby game, during 'off-side' games, the ball can be passed in any direction (i.e. to 'off-side' players). Within each of the three groups, players were divided into two teams of nine players, ensuring an even spread of playing positions. Each game consisted of two 10 min halves separated by a 2 min rest interval played on a grass training pitch in a standardised (50 m x 80 m) playing area. The 'off-side' game utilised the same rules as those reported previously [20]. The 'off-side' game permitted each team to have three 'plays' while in possession of the ball. A 'play' ended when the player in possession of the ball was touched by a defender with two hands. The ball was turned over when the attacking side had completed three 'plays', or if an error was committed. Every 2 min of each game players performed a contact bout (eight contact bouts in total), with players allowed 5 s to find their partner. The only difference between the three games was the number of wrestles in each contact bout. In game 1, players performed a single contact effort each bout (8 in total); game 2 involved two contact efforts each bout (16 in total); game 3 involved 3 contact efforts each bout (24 in total). From a standing position, the players were asked to perform a single shoulder contact, before being given 5 s to wrestle their partner onto their back. In games 2 and 3 when players performed multiple contacts, each 5 s contact was separated by 2 s of rest. All players received coaching on wrestling techniques as part of their training and were familiar with this contact drill. Similar simulated contacts have good reproducibility in rugby league players [9]. After each contact period, the game resumed. Other than the number of contact bouts, there was no difference in the rules, verbal encouragement, pitch size, player number, or match duration between games.

4.3.3.5 Global Positioning System Analysis

Game movements were assessed using GPS microtechnology devices. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included 100 Hz tri-axial accelerometers and gyroscopes to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and subsequently analysed (Sprint, Version 5.1.1, Catapult Sports, VIC, Australia). Data were categorised into low-speed activity (0-3.5 $m \cdot s^{-1}$), moderate-speed running (3.6-5.0 $m \cdot s^{-1}$) and high-speed running (≥5.1 $m \cdot s^{-1}$).[2] Data were divided into 5 min blocks for analysis in order to determine the changes in running performance during each game. Player Load™ Slow (<2 $m \cdot s^{-1}$) was used to determine the load associated with the non-running components (i.e. physical contact) of the games [167]. These units offer valid and reliable estimates of movements common in rugby league [160, 164].

4.3.3.6 Statistical Analyses

Due to the varying length of each contact period (single-contact = 10 s [5 s to find partner; 1 x 5 s wrestle]; double-contact = 17 s [5 s to find partner; 2 x 5 s wrestle; 1 x 2 s rest]; triple-contact = 24 s [5 s to find partner; 3 x 5 s wrestle; 2 x 2 s rest]) only active playing time (less the contact periods) was analysed; distances covered were expressed relative to ball in play time. Pearson's product moment correlation coefficient was used to determine the relationships between physical qualities and movements during each game, correlations from 0.1-0.30, 0.31-0.50, 0.51-0.70, and > 0.71 were deemed small, moderate, large and very large respectively [176]. The practical meaningfulness of any differences in movement demands between the three games was determined using magnitude based inferences. The likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x the between subject standard deviation. Thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; ≥99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± 95% confidence intervals (CI); the significance level was set at $p<0.05$.

4.3.4 Results

The group means for the 30-15IFT, back squat 1RM, and bench press 1RM were 19.1 ± 1.2 $km \cdot h^{-1}$; 154.0 ± 21.5 kg; and 124.0 ± 15.0 kg, respectively.

The average relative distance covered during the first and second halves of each game is presented in Figure 4.4. There was little difference for whole game relative distance between the single-, double- and triple-contact games (ES = 0.21 to -0.57). There was no difference in the relative distance covered between games during the first half (ES = 0.27 to -0.34). There were only small changes in relative distance from first half to second half in the single- (ES = -0.43 ± 1.0; likelihood = likely, 83%) and double-contact games (ES = -0.51 ± 1.0; likelihood = likely, 90%), and moderate reductions in the triple-contact game (ES = -1.07 ± 1.0; likelihood = very likely, 99%). The relative distance covered in the second half of the double- (ES = -0.61 ± 1.0; likelihood = likely, 95%) and triple-contact (ES = -0.69 ± 1.0; likelihood = very likely, 96%) games was moderately lower than the second half of the single-contact game.

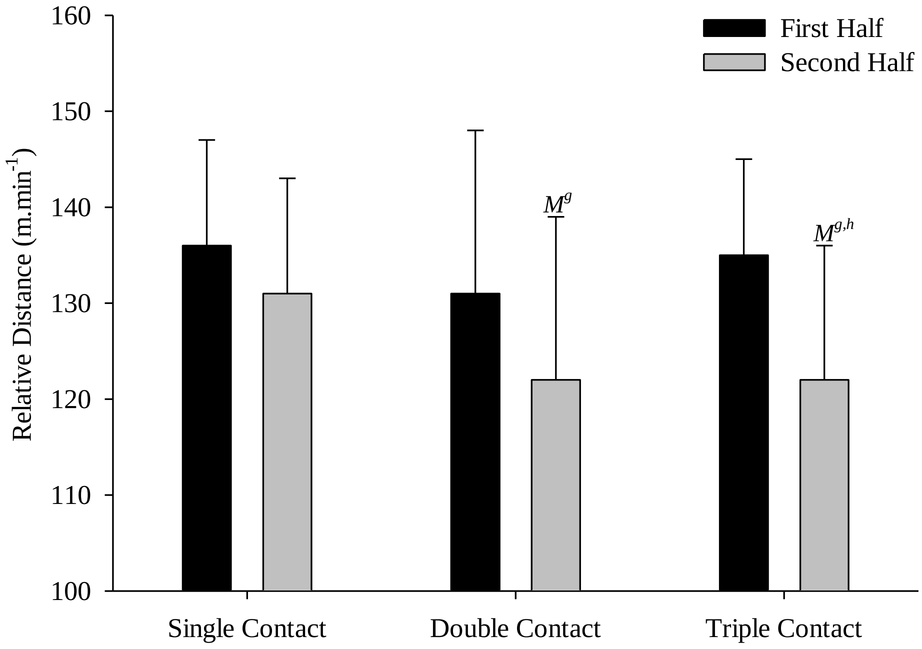

Figure 4.4. Relative distance covered during each half of the single, double, and triple-contact game. M^h Denotes a moderate effect size difference (0.61-1.19) between first and second half. M^g Denotes a moderate effect size difference between the second halves compared to the single-contact game. Data are presented as means ± SD.

Changes in relative distances covered during each game are presented in Figure 4.5. During the single-contact game, there was little change in playing intensity with only moderate reductions in relative distance during the final 5 min (16-20 min) (ES = -0.73 ± 1.0; likelihood = likely, 96%). In the double-contact game, there were moderate reductions in relative distance during the 6-10 min (ES = -0.85 ± 0.78; likelihood = very likely, 96%) and 11-15 min periods (ES = -0.97 ± 0.83; likelihood = very likely, 98%), and large reductions in the 15-20 min period (ES = 1.93 ± 1.0; likelihood = almost certain, 100%). There was little change in low-speed activity (ES = 0.08 to -0.52) and moderate-speed running (ES = -0.18 to -0.48) in the double-contact game, and large reductions in high-speed running during 6-10 min period (High-speed: ES = -1.24 ± 1.0; likelihood = very likely, 98%). In the triple-contact game, there were small reductions in relative distance during 6-10 min (ES = -0.48 ± 1.0; likelihood = likely, 87%), and large reductions during the 11-15 min (ES = -1.26 ± 1.0; likelihood =

almost certain, 100%), and 16-20 min periods (ES = -1.28 ± 1.0; likelihood = almost certain, 100%). There were moderate reductions in low-speed activity during the 6-10 min (ES = -0.81 ± 1.0; likelihood = very likely, 98%) and 11-15 min (ES = -1.14 ± 1.0; likelihood = almost certain, 100%). Reductions in moderate-speed running were seen during the final 10 min (11-15 min: ES = -0.67 ± 1.0; likelihood = likely, 88%; 16-20 min: ES = -1.24 ± 1.0; likelihood = almost certain, 100%) of the triple-contact game. There was large reductions in high-speed running during 16-20 min (ES = -1.52 ± 1.0; likelihood = almost certain, 100%).

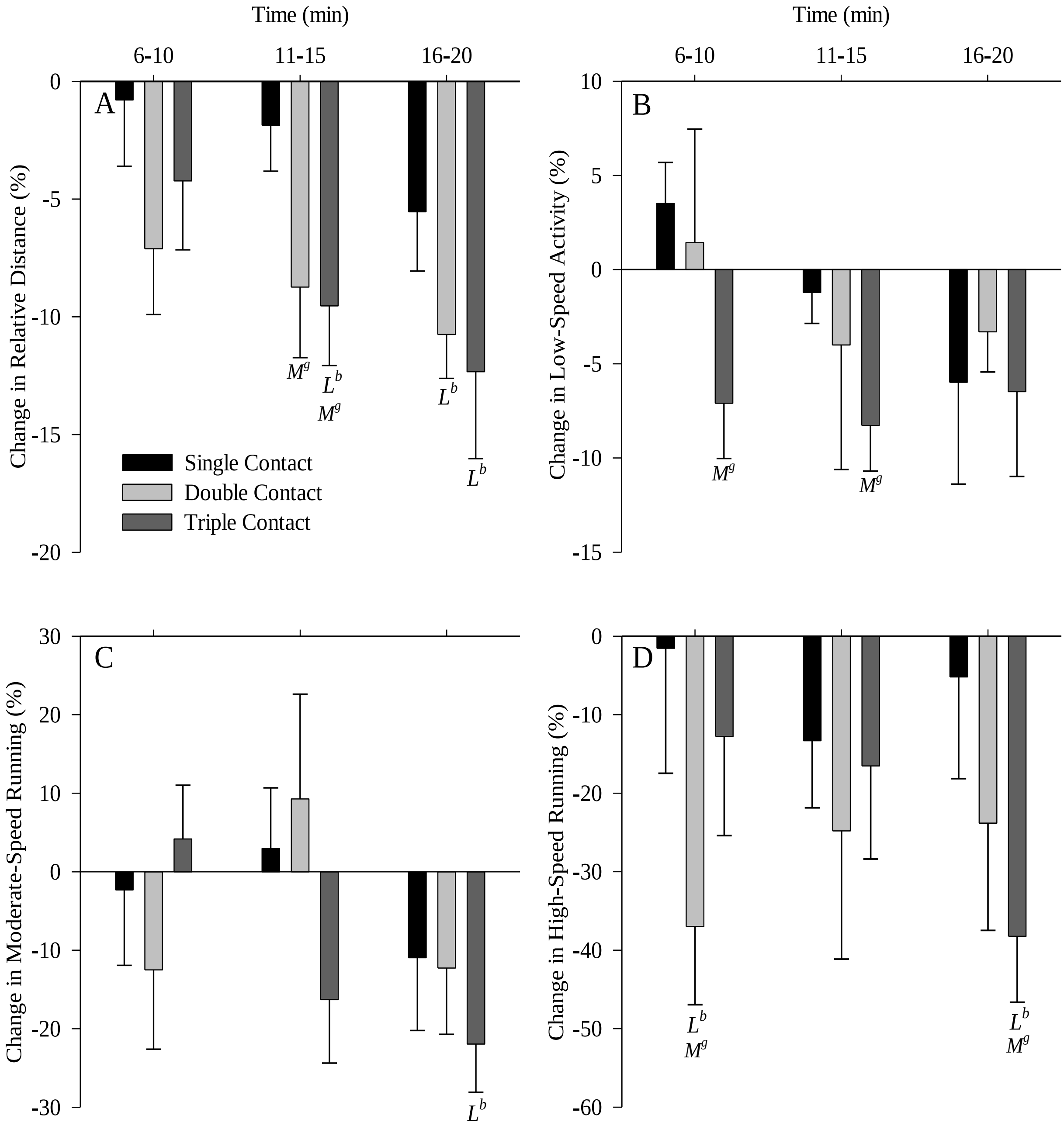

Figure 4.5. Percentage change in (A) relative distance; (B) low-speed activity; (C) moderate-speed running; and (D) high-speed running compared with the 0-5 min period during the single, double, and triple-contact games. M^g Denotes a moderate effect size difference (0.61-1.19) from the single-contact game. L^b Denotes a large effect size difference (≥1.20) from 0-5 min. Data are presented as means ± SE.

Player Load™ Slow increased with the contact demands of each game (Figure 4.6). Player Load™ Slow was greater in the triple-contact game than the single-contact game during each 5 min period (ES = 0.68 to 1.00; likelihood = likely to almost certain, 88-100%), and greater than the double-contact game in the 0-5 min period (ES = 0.74 ± 1.0; likelihood = very likely, 96%). There was only small reductions in Player Load™ Slow during the single- and double-contact games (ES = -0.11 to -0.18). In the triple-contact game, there were moderate (ES = -0.65 ± 1.0; likelihood = likely, 86%) and small reductions during the 6-10 and 11-16 min periods respectively, and large reductions in the final 5 min period (ES = -1.29 ± 1.0; likelihood = almost certain, 100%).

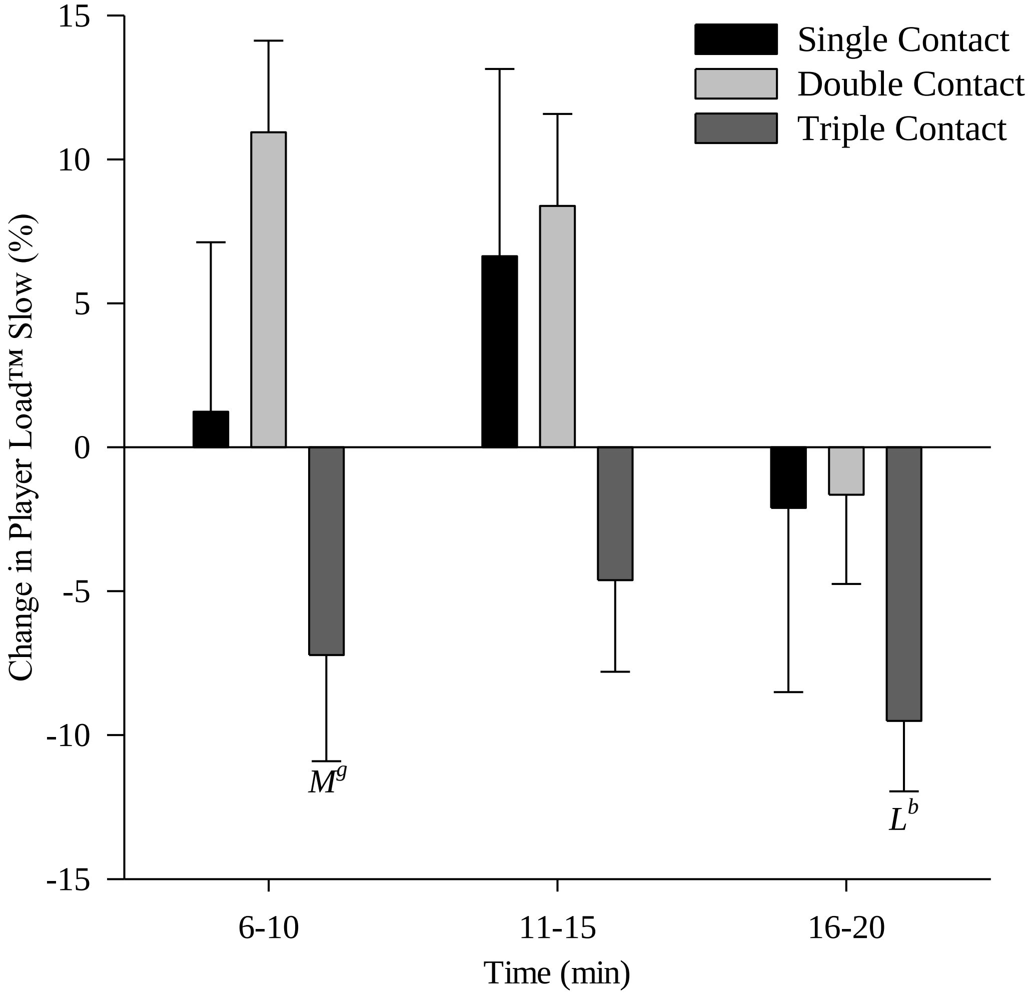

Figure 4.6. Percentage change in Player Load™ Slow compared to the 0-5 min period during the single, double, and triple-contact games. M^g Denotes a moderate effect size difference (0.61-1.19) from the single-contact game. L^b Denotes a large effect size difference (≥1.20) from baseline. Data are presented as means ± SE.

The relationships between high-intensity running ability (30-15IFT) and lower- (Squat 1RM) and upper-body (Bench 1RM) muscular strength are highlighted in Table 4.3. Lower- and upper-body strength were not associated with distances covered during any of the games ($p>0.05$). Performance on the 30-15 IFT was negatively associated with low-speed distance in the single-contact game and positively associated with moderate- and high-speed running on the single and double-contact game. 30-15IFT performance was not associated with distances covered in the triple-contact game. As the number of contact efforts increased in each game, the relationship between 30-15 IFT performance and relative running distance covered during the games decreased.

Table 4.3. Relationship among physical qualities and distances covered at low, moderate, and high-speeds during the three small-sided games. †

	Distance			Low-speed activity			Moderate-speed activity			High-speed running		
	Single	Double	Triple	Single	Double	Triple	Single	Double	Triple	Single	Double	Triple
30-15IFT	0.33	-0.28	0.41	-0.57*	-0.28	0.31	0.57*	0.47*	0.18	0.72**	0.75*	0.20
Squat 1RM	0.13	0.10	0.17	-0.20	-0.08	0.29	0.10	0.13	-0.19	0.38	0.33	0.01
Bench 1RM	0.25	0.19	0.27	-0.04	0.11	0.22	0.10	0.03	0.01	0.36	0.27	0.11

† Data are presented as Pearson’s product moment correlation coefficients. * Denotes significant at the 0.05 level; ** denotes significant at the 0.01 level. Single = single-contact game; Double = double-contact game; Triple = triple-contact game. Low-speed activity = 0-3.5 $m \cdot s^{-1}$; moderate-speed running = 3.6-5.0 $m \cdot s^{-1}$; high-speed running = ≥5.1 $m \cdot s^{-1}$. 30-15 IFT = 30-15 Intermittent Fitness Test; 1RM = 1 repetition maximum.

4.3.5 Discussion

The aim of this study was to determine the influence the number of contact efforts in a single bout had on running performance during small-sided games, as well as assessing the relationships between physical qualities and distances covered in each game. The findings of our study confirmed our hypotheses; as the number of contact efforts increased, there were greater reductions in high-speed running and weaker relationships between high-intensity running ability and distances covered during each game. This study demonstrates that making players perform multiple contact efforts in close proximity to one another causes greater reductions in high-speed running. In addition, high-speed running ability appears important for performance when contact demands are low, however as the contact demands increase; high-intensity running ability and performance dissociate. Developing high-intensity running ability alone is likely to leave players underprepared for the most intense contact and running demands of competition.

There was little change in relative distance covered during the single-contact game, whereas, when players performed two or three contacts in each bout, there were greater reductions in game intensity. The addition of single contact efforts to running activities results in greater reductions in repeated-sprint performance [9] and low-speed distance during small-sided games [20]. However, in match-play, players are often required to perform multiple contact bouts in quick succession [25, 76]. The present investigation highlights that when players are required to perform multiple contact efforts in succession, there are greater reductions in running performance.

Of interest is that although there were large differences between the single and multiple contact games (i.e. single *vs.* double and triple), there were more subtle differences between the multiple contact games (i.e. double *vs.* triple). The largest reductions in relative distance between the first and second half were seen in the triple-contact game, followed by the double-contact game. The reductions in relative distance observed in the double-contact game were largely brought about by decreased distances covered at high-speed, whereas in the triple-contact game, the reductions in relative distances occurred due to a combination of reduced low-speed activity as well as moderate- and high-speed running. However, in the double-contact game, there was an initial large reduction in high-speed running during the 6-10 min period before attenuating this reduction, preventing no further deterioration in high-speed running beyond the 6-10 min period. Conversely, the triple-contact game showed progressive reductions in high-speed running as the game advanced, culminating in large reductions in the final 5 min period. There are several possible explanations for the greater reductions in relative distance, and high-speed running in particular, observed during the multiple contact games. Firstly, players may prioritise the contact efforts, over the running efforts of the game [20], allowing them to preserve energy and finish the game in a reasonable physical state. Despite this potential strategy, the large reduction in high-speed running observed in the final 5 min of the triple-contact game suggest significant player fatigue [20, 177]. In the double-contact game, the initial greater distance covered at high-speed before reducing to levels similar to the triple- and single-contact games is indicative of a variable pacing strategy and transient fatigue [13, 85]. Although players are likely to adopt some kind of pacing strategy, it is important to consider that contextual factors (e.g. line breaks, points scored) during each game may also influence the observed results. Moreover, it is worth noting that players regularly performed the single contact games during training, but were less familiar with the triple contact game. Prior knowledge of an event appears important for setting an appropriate pacing strategy [13]. Therefore, due to limited exposure to the multiple contact games, players may have set an inappropriate pacing strategy that resulted in high levels of fatigue towards the end of the game and subsequent reductions in high-speed running during the final 5 min. This information highlights that when players are required to perform multiple contact efforts in quick succession, there is significant fatigue induced. There are greater performance reductions towards the end of the game with an increased contact demand (i.e. in the triple-contact game). It can be argued that players need to be exposed to these extreme contact and running demands regularly in order for them to develop appropriate conditioning and pacing strategies to minimise the development of fatigue.

Player Load™ Slow was used to estimate the non-running components of each game. Player Load™ Slow was greater in the double- and triple-contact games compared to the single-contact game. The greatest Player Load™ Slow was observed in the first 5 min of the triple-contact game and only showed small reductions in the subsequent periods, before a moderate reduction in the final 5 min of the game. The greater Player Load™ Slow observed in the multiple contact games suggests that there was a greater non-running component (and potentially contact load) associated with these games. Indeed, the greater contact load imposed on players would partially explain the greater reductions in running performance seen in these two games. The changes in Player Load™ Slow during each game were smaller than the reductions in running over each game. Potentially, players prioritised energy towards performing the contact efforts over running efforts, which supports previous research.[20] Alternatively, Player Load™ Slow may not be as sensitive to changes in performance as the running metrics, although standardised differences, such as ES should be used to determine this. It is important to assess the non-running or contact demands of training and competition as opposed to assessing distances covered, in isolation.

High-intensity running ability was positively associated with moderate-speed and high-speed running during the single and double-contact games, and negatively associated with low-speed activity during the single-contact game (Table 9). However, there was no association with distances covered during the triple-contact game. Lower- and upper-body strength were not associated with distances covered during any of the games. These results suggest that when the contact demands are low, high-speed running ability is closely linked to distances covered at moderate- and high-speeds. The relationship between high-intensity running ability and distance covered diminished as the contact demands increased, which is consistent with the findings of others [24, 28]. Although well-developed high-intensity running ability is important for performance and success in rugby league [28], solely developing this quality is likely to leave players underprepared for the most intense contact and running demands of competition.

4.3.6 Conclusions

When players engage in a single-contact effort in a contact bout, they are able to maintain running performance close to baseline, but when multiple contact efforts are performed in the same contact bout, there are large reductions in running performance. Although the reductions in performance were similar between the double- and triple-contact games in the present study, there was a greater reduction in performance in the triple-contact game, especially the final 5 min. Players appeared to prioritise contact efforts over running efforts, highlighted by smaller reductions in Player Load™ Slow; this may reflect the fact that physical contact is central to success in rugby league. There were strong relationships observed between 30-15IFT and running performance in the single and double-contact games, but not in the triple-contact game. This suggests that high-intensity running ability is closely linked to running performance when contact demands are low, but this relationship weakens as contact demands increase. As such, developing running qualities alone are likely to leave players underprepared for the most intense contact and running demands of competition. It is important to note that skill performance was not assessed in the present study. Whilst contact clearly impacts on physical performance, it would be interesting to determine the influence physical contact has on skill execution in rugby league players. In addition, the active playing time was different in each game, which may affect the opportunities to perform high-speed activity in the double and triple contact games. Future research could normalise active playing time to allow for more direct comparisons between games.

4.3.7 Practical Applications

- Developing running fitness alone does not prepare players for the intense contact and running demands of competition.
- Performing multiple contact efforts in quick succession is physically demanding for players and results in greater reductions in running performance. In order to minimise these reductions, coaches should develop drills that replicate the most intense contact demands of competition whilst requiring players to maintain running performance.
- Targeting players in attack so they perform at least two consecutive contact efforts is likely to result in greater reductions in running performance.

4.3.8 Acknowledgements

The authors would like to thank the players and coaching staff of Norths Devils Rugby League Club who participated in this study. No sources of funding were used to conduct this research.

4.4 Study 4: Pacing strategies adopted during an intensified team sport competition depend on playing standard and physical fitness

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, and Jenkins DG. Pacing strategies adopted during an intensified team sport competition depend on playing standard and physical fitness. *Int J Sports Physiol Perform*, 2015, March 10.

4.4.1 Abstract

The purpose of this study was to assess the influence of playing standard and physical fitness on pacing strategies during a junior team sport tournament. A between-group, repeated measures experimental design was used. Twenty-eight junior team sport players (age 16.6 ± 0.5 years; body mass 79.9 ± 12.0 kg) from a high-standard and low-standard team, participated in a junior rugby league tournament, competing in 5 games over 4 days (4 x 40 min and 1 x 50 min game). Players wore global positioning system microtechnology during each game to provide information on match activity profiles. The Yo-Yo intermittent recovery test (level 1) was used to assess physical fitness prior to the competition. High-standard players had an initially higher pacing strategy than the low-standard players, covering greater distances at high- (ES = 1.32) and moderate-speed (ES = 1.41) in game 1, and moderate-speed (ES = 1.55) in game 2. However, low-standard players increased their playing intensity across the competition (ES = 0.57 to 2.04). High-standard/high-fitness players maintained a similar playing intensity, whereas high-standard/low-fitness players reduced their playing intensities across the competition. Well-developed physical fitness allows for a higher intensity pacing strategy that can be maintained throughout a tournament. High-standard/low-fitness players reduce playing intensity, most likely due to increased levels of fatigue as the competition progresses. Low-standard players adopt a pacing strategy that allows them to conserve energy to produce an ‘end-spurt’ in the latter games. Maximising endurance fitness across an entire playing group will maximise playing intensity and minimise performance reductions during the latter stages of a tournament.

4.4.2 Introduction

Pacing describes the efficient use of energy resources during exercise so that all available energy is used without compromising performance or physiological failure of any one physiological system before the cessation of the event [168]. It is believed that pacing strategies are controlled at both the conscious and subconscious level [170]. Prior to exercise, athletes will set a pacing strategy (or intensity) based on previous knowledge of the event [13]. Throughout exercise, sensory information from the muscles, cardiovascular system and other receptors influence centrally controlled conscious decisions to either increase, decrease, or maintain exercise intensity [170]. It is well documented that athletes from 'continuous' sports use pacing strategies [13]. In team sports however, the stochastic nature of match-play and continually changing contextual factors (e.g. covering a line break) make a closely controlled pacing strategy more difficult to implement. Despite this, players appear to employ pacing strategies to manage energy in order to prevent excessive threats to homeostasis and complete game tasks whilst remaining in a reasonable physical state [16, 170]. Indeed, research from sports such as rugby league [15, 16], Australian rules football [17, 18], and soccer,[19] have shown players modify their activities as a match progresses; they reduce 'non-essential' low-speed activities to preserve energy for the completion of high-intensity efforts (e.g. high-speed running, sprinting, and tackling) [17, 18, 20]. It is clear that numerous factors influence pacing strategies during self-paced events, including changes in core temperature [18, 21], knowledge of exercise end-point [14], bout duration [16, 22], match outcome [15], substrate availability [12], and match activities [20]. Despite this there are currently a number of unknowns, such as whether tournaments or periods of congested fixtures, playing standard and physical fitness influence pacing strategies employed by players.

Players from a wide range of team sports regularly compete in tournaments where they are required to play a number of games within a short period of time [29, 150]. Whilst pacing strategies during single games have been examined, no study has explored the pacing strategies employed during periods of congested fixtures or tournaments. These pacing strategies may differ to those seen during regular competition; players may adjust match activities in an attempt to minimise post-match fatigue that are linked to reductions in physical and technical match activities [30, 150]. Previous work found that senior players adopted an even-paced strategy across a tournament despite reductions in high-speed running [30]. Junior players on the other hand, show reductions in overall match-intensity with reduced high- and low-speed activity across a tournament [150]. A potential reason for this could be that junior players are likely to have less experience of such competitions and therefore may be unaware of the appropriate pacing strategy to adopt. Alternatively, or in addition to, these players may be physically under-developed so are unable to reproduce match activities with such limited recovery. Despite this, both of these studies were conducted in single teams and therefore did not take into account how playing standard or physical fitness may affect pacing strategies.

In semi-elite players, both successful and less-successful teams show reductions in overall running intensity in the second-half of matches, with little difference between teams [72]. During a junior rugby league tournament, match intensity has been shown to increase with playing standard [60], but as tournament averages were only reported, it is unclear how intensities changed between games are therefore, any information on potential pacing strategies employed. As such, it is still unclear if pacing strategies are influenced by playing standard during tournaments or periods of congested fixtures.

Research from team sports has highlighted the close link between physical fitness and match activity profiles [28, 139, 182]. In rugby league [28, 139] and soccer [182], well-developed high-intensity running ability results in more total and high-speed distance during match-play. Despite this, the influence of physical fitness on activity profiles and pacing strategies during a tournament are unknown. With this in mind, the aim of this study was to determine whether the between-match pacing strategy employed during a junior rugby league tournament differed based on playing standard and physical fitness. It was hypothesised that (1) high-standard players would adopt a higher pacing strategy across the competition compared with low-standard players and (2) as the tournament progressed, players with high-fitness would show smaller between match reductions in playing intensity compared with low-fitness players.

4.4.3 Methods

4.4.3.1 Design

To test our hypotheses, a between-group, repeated measures experimental design was used. Match activity profiles were assessed during a junior rugby league tournament using global positioning system (GPS) microtechnology units. Players from two teams competing in the top division (high-standard) and bottom division (low-standard) of the competition formed the sample for this study. Physical fitness was assessed prior to the tournament using the Yo-Yo intermittent recovery rest (IRT) level 1. Based on Yo-Yo IRT performance, a median spilt was used to divide players into high- and low-fitness groups to determine the influence of physical fitness on between-match pacing strategies during a tournament [78]. Players were matched for playing position (forwards and backs) before being divided into experimental groups. This ensured that there were an equal number of forwards and backs in each group. This provided us with four experimental groups based on Yo-Yo IRT performance: high-standard/high-fitness, high-standard/low-fitness, low-standard/high-fitness, and low-standard/low-fitness. The Yo-Yo IRT has the ability to discriminate between starters and non-starters in rugby league players, suggesting it is a valid measure of physical fitness [24].

4.4.3.2 Subjects

Twenty-eight junior rugby league players (age 16.6 ± 0.5 years; body mass 79.9 ± 12.0 kg) competing for two different schools in the 2014 Confraternity Shield tournament participated in the study. The Confraternity Shield is the largest state-wide school-boy tournament in Queensland involving more than 40 schools. One team was competing in the first division of the competition, and represented the high-standard team (*entire team,* n = 15; age 16.6 ± 0.5 years; body mass 76.9 ± 8.7 kg; *high-fitness group,* n = 7; age 16.5 ± 0.5 years; body mass 80.4 ± 8.1 kg; *low-fitness group,* n = 8; age 16.8 ± 0.5 years; body mass 74.4 ± 8.9 kg), the second team was competing in the third division, representing the low-standard team (*entire team,* n = 13; age 16.6 ± 0.5 years; body mass 83.3 ± 14.5 kg; *high-fitness group,* n = 6; age 16.5 ± 0.4 years; body mass 79.0 ± 11.5 kg; *low-fitness group,* n = 7; age 16.8 ± 0.6 years; body mass 87.1 ± 16.6 kg). The tournament took place in July, three months into the competitive season. All players were free from injury at the time of testing; nutritional intake throughout the competition was prescribed by team management staff of the respective schools; water was available *ad libitum*. Before the study, players attended a familiarisation session and received an information sheet outlining experimental procedures, and the associated risks and benefits of participation; written informed consent was obtained from each player and their legal guardian. The study was approved by the Australian Catholic University ethical review board for human research.

4.4.3.3 Protocol

Ten days prior to the tournament, the Yo-Yo IRT level 1 was used to assess physical fitness [183]. The test was performed at 15:00 hrs on a grassed playing surface at the start of a training session; players wore studded boots and training kit to complete the test. Players were asked to maintain their normal diet and refrain from physical activity during the 24 hours prior to the test. Some of the players were unfamiliar with the test so the first two levels of the test were incorporated into the warm-up to familiarise players with the test protocol. The typical error of measurement (TE) for this test is 4.9% [183].

The first 4 games of the tournament were 40 min (2 x 20 min halves), with the final game being 50 min (2 x 25 min halves) in duration. Two games were played on both days 1 and 2, no games on day 3 and one game on day 4 totalling 5 games (210 min) over a 4 day period. The average temperature, rainfall, and humidity over the competition period were 20.6 ± 2.2 °C, 0.00 ± 0.00 mm, and 51.0 ± 15.3%, respectively. Only players that competed in at least 50% of each game were included in the data analysis; two players, both from the low-standard team, were excluded from the analysis as they sustained injuries and subsequently did not compete in 50% of each game. The high-standard team won 3 from 5 games, scoring 98 points and conceding 72; the low-standard team won 5 from 5 games, scoring 112 points and conceding 52. At the end of each day, the coaching staff of both teams led their players through a pool recovery session that involved low-intensity dynamic movements for the upper- and lower-body; these sessions lasted approximately 10-15 min.

4.4.3.4 Match Activities

Activity profiles during competition were assessed using GPS analysis. Prior to the warm-up before each game, players were fitted with the GPS vest and unit; the unit was switched on, and inserted into a padded compartment at the rear of the vest, positioned between the shoulder blades. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included a tri-axial accelerometer and gyroscope sampling at 100 Hz to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and analysed using software provided by the manufacturer (Sprint, Version 5.1.1, Catapult Sports, VIC, Australia). Non-playing minutes were omitted from the analysis. Data were categorised into low (0-3.5 $m \cdot s^{-1}$), moderate (3.6-5.0 $m \cdot s^{-1}$) and high speed (≥5.1 $m \cdot s^{-1}$) movement bands [62]; the number and nature of collisions were categorised as described previously [2]. In addition, relative match-speed was calculated for each game by expressing relative intensity ($m \cdot min^{-1}$) in relation to the final speed reached on the Yo-Yo IRT. Repeated high intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration (≥2.78 $m \cdot s^{-2}$), high-speed, or impact efforts with less than 21 s between each effort [2]. These units offer suitable reliability for quantifying movements commonplace in rugby league [160, 164]. Additionally, 30 min after each game, rating of perceived exertion (RPE) was recorded using a modified RPE scale (CR-10) to rate how hard players perceived each game. The RPE score was then multiplied by the number of minutes played to determine session RPE as a measure of internal load [172]. This method of assessing internal loads has shown to have appropriate levels of validity and reliability (TE = 4.0%) in rugby league players [184].

4.4.3.5 Statistical Analyses

Differences in activity profiles between the high- and low-standard and high- and low-fitness playing groups and changes over time were determined using traditional null hypothesis testing, and magnitude based inferences. A three-way group (high- *vs.* low-standard) x time (Game 1 *vs.* 2 *vs.* 3 *vs.* 4 vs. 5) x fitness (High Yo-Yo *vs.* Low Yo-Yo) repeated measures ANOVA (SPSS 19.0, SPSS Inc, Chicago, IL, USA) was used to determine changes in activity profiles between playing standards and fitness groups. The significance level was set at $p<0.05$. Based on the real-world relevance of the results, magnitude based inferences were also used to assess the meaningfulness of any differences. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x between subject standard deviation. Based on 90% confidence intervals, the thresholds used for assigning qualitative terms to chances were as follows: $<1\%$ almost certainly not; $<5\%$ very unlikely; $<25\%$ unlikely; $<50\%$ possibly not; $>50\%$ possibly; $>75\%$ likely; $>95\%$ very likely; $>99\%$ almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was $\geq75\%$. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]. ES of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large, respectively [176]. Pearson's product moment correlation coefficient were used to assess the relationship between RPE and match activity variables; correlations of 0.1-0.3, 0.31-0.5, 0.51-0.7, and >0.7 were determined small, moderate, large and very large respectively [176]. Data are reported as means ± standard deviation (SD) unless otherwise stated.

4.4.4 Results

The changes in match activity profiles across the competition for both high- and low-playing standards are shown in Figure 4.7 and Table 4.4. There was a non-significant, main effect of playing standard ($p = 0.058$) and game ($p = 0.264$); however there was a significant group x time interaction ($p = 0.013$) for relative distance. There was a large difference in relative distance covered during game 1 and game 2 between playing standards, with high-standard players covering greater distances at high- (ES = 1.32; Likelihood = 99%, Very Likely) and moderate-speeds (ES = 1.41; Likelihood = 100%, Almost Certain) in game 1, and moderate-speed (ES = 1.55; Likelihood = 100%, Almost Certain) in game 2. After this point, the high-standard players maintained a similar playing intensity across each game except for game 5, where there was a large reduction in relative distance through reductions in high- (ES = 1.34; Likelihood = 99%, Very Likely) and moderate-speed running (ES = 1.22; Likelihood = 99%, Very Likely). Conversely, the low-standard players showed a gradual increase in playing intensity across each game of the competition (ES = 0.57 to 2.04). This was primarily achieved through increases in low-speed activity (ES = 0.55 to 1.79). When the match speed was expressed relative to final Yo-Yo speed (Table 4.4), high-standard players had greater relative match-speeds in game 1 (ES = 0.75; Likelihood = 90%, Likely) and 2 (ES = 0.74; Likelihood = 90%, Likely) and maintained a similar intensity to game 1 across the competition. Low-standard players showed increases in relative match-speed as the tournament progressed; in game 5 they had greater intensities than high-standard players (ES = 0.92, Likelihood = 95%, Very Likely). There was little change in the frequency of physical collisions between games ($p = 0.703$; Figure 4.7B); there was a greater frequency of physical collisions in the high-standard group ($p = 0.049$), particularly in games 1 (ES = 0.65; Likelihood = 93%, Likely) and 2 (ES = 0.88; Likelihood = 93%, Likely) compared with the low-standard group. A similar trend was seen for RHIE bouts, with little change in RHIE frequency (ES = -0.34 to 0.50) across games in both playing standards (Figure 4.7C). High-standard players had a greater frequency of RHIE bouts across the first four games of the competition (ES = 0.61 to 0.95; $p = 0.089$). Internal loads were greater in the high-standard group across the tournament with large effect size differences in game 2 (ES = 1.40; Likelihood = 98%, Very Likely), 4 (ES = 1.81; Likelihood = 100%, Almost Certain), and 5 (ES = 1.60; Likelihood = 100%, Almost Certain) compared with the low-standard group (Table 4.5).

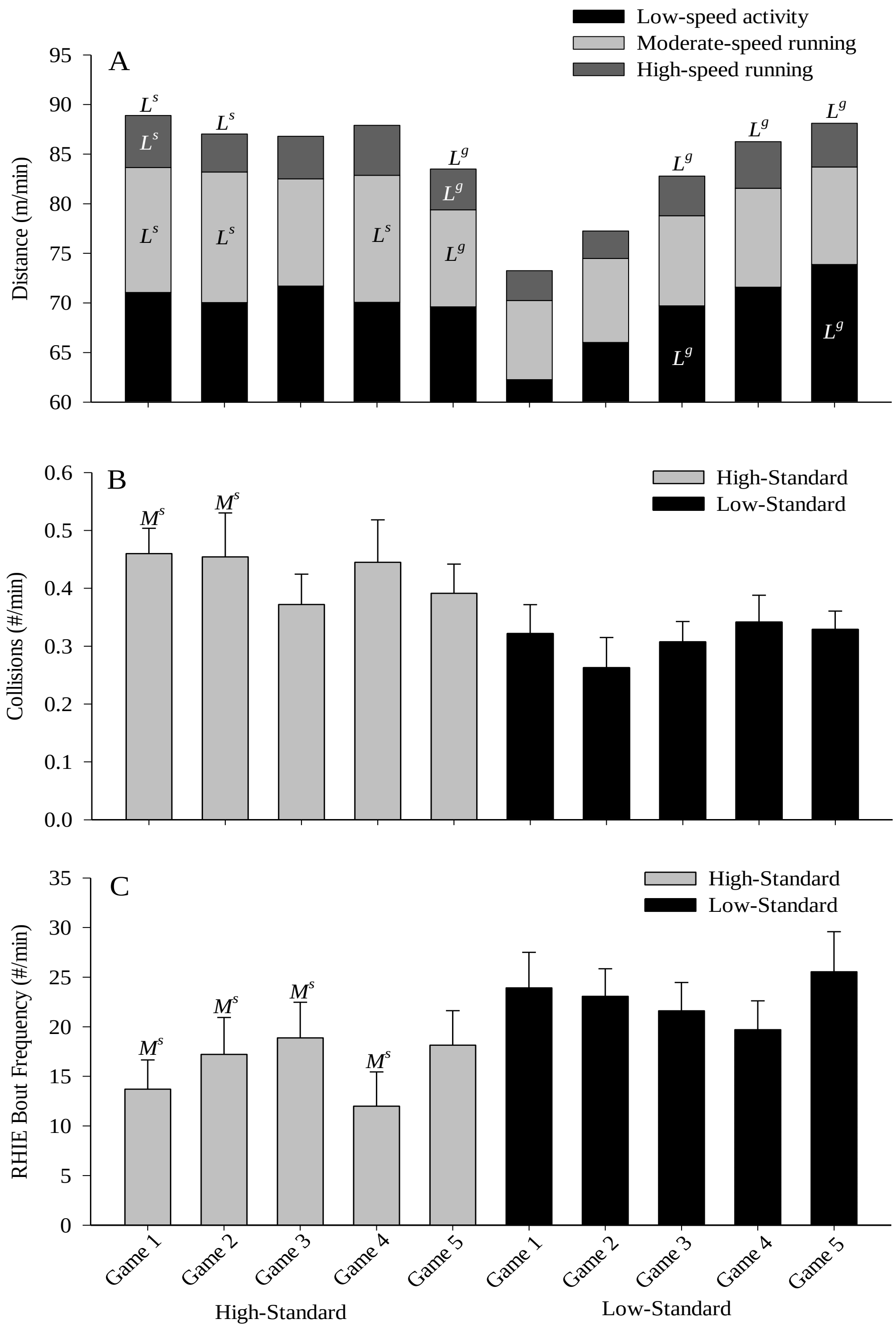

Figure 4.7. Changes in (A) relative distance, (B) collisions per minute, and (C) repeated high-intensity effort bout frequency during each game of the competition in the high-standard and low-standard players. Data are presented as means ± SE. Figure 4.7A, L^s denotes a large effect size difference (≥1.20) between playing standards for the same fixture; L^g denotes a large effect-size difference from Game 1. Figure 4.7B and C, M^s denotes a moderate effect size difference (0.61-1.19) between playing standards for the same fixture.

Table 4.4. Relative match speed as a percentage of the final speed reached on the Yo-Yo Intermittent Recovery Test Level 1 during each game of the competition. †

Group	**Game 1 (%)**	**Game 2 (%)**	**Game 3 (%)**	**Game 4 (%)**	**Game 5 (%)**
High standard	35 ± 2[b]	35 ± 3[b]	34 ± 3	34 ± 3	33 ± 3[b]
Low standard	30 ± 9	33 ± 3	34 ± 4	35 ± 5	36 ± 3
High-standard/high-fitness	36 ± 3	35 ± 3	35 ± 4	35 ± 3[c]	35 ± 3[c]
High-standard/low-fitness	34 ± 9	34 ± 9	33 ± 8	31 ± 9	31 ± 9
Low-standard/high-fitness	32 ± 4[d]	33 ± 3[d]	35 ± 3	35 ± 2	36 ± 4[a]
Low-standard/low-fitness	33 ± 3[d]	32 ± 3[d]	34 ± 5	35 ± 6	36 ± 3

† Data are presented as means ± SD. [a] Denotes a large effect size (≥1.20) difference from Game 1; [b] denotes a moderate effect size (0.61-1.19) difference from low-standard; [c] denotes a moderate effect size difference from low-fitness players; [d] denotes a moderate effect size difference from high-standard/high-fitness players.

Table 4.5. Internal loads for each game of the tournament. †

Group	**Game 1 (AU)**	**Game 2 (AU)**	**Game 3 (AU)**	**Game 4 (AU)**	**Game 5 (AU)**
High standard	160 ± 64	147 ± 54[b]	167 ± 93	198 ± 45[b]	219 ± 62[b]
Low standard	111 ± 49	82 ± 37	95 ± 56	106 ± 55	126 ± 54
High-standard/high-fitness	143 ± 61	170 ± 38	224 ± 43[c]	226 ± 34[c]	242 ± 76
High-standard/low-fitness	169 ± 71	144 ± 48	168 ± 49	153 ± 67	221 ± 79
Low-standard/high-fitness	107 ± 48	81 ± 29	118 ± 66	139 ± 80	116 ± 22
Low-standard/low-fitness	104 ± 47	84 ± 45	101 ± 57	94 ± 44	116 ± 24

† Data are presented as means ± SD. Internal load = rating of perceived exertion x playing minutes. [a] Denotes a large effect size (≥1.20) difference from Game 1; [b] denotes a large effect size (≥1.20) difference from low-standard; [c] denotes a large effect size (≥1.20) difference from low-fitness players.

Players from each standard were divided into high- and low-fitness groups and the results are shown in Figure 4.8 and Table 4.4. High-standard/high-fitness players maintained overall match playing intensity across the competition despite moderate reductions in moderate-speed running in game 3 (ES = -1.00; Likelihood = 86%, Likely) and 5 (ES = -1.10; Likelihood = 91%, Likely), and a large reduction in high-speed running in game 2 (ES = -1.30; Likelihood = 90%, Likely). Conversely, high-standard/low-fitness players showed reductions in overall playing intensity in games 2 (ES = -1.29; Likelihood = 94%, Likely), 3 (ES = -0.76; Likelihood = 68%, Possibly), 4 (ES = -1.37; Likelihood = 97%, Likely), and 5 (ES = -1.87; Likelihood = 100%, Almost Certain), primarily through reductions in low-speed activity (ES = -0.68 to -0.74) and high-speed running (ES = -0.63 to -0.78). This translated to small reductions in relative match-speed (ES = -0.30 to -0.41) in games 4 and 5 of the competition, which were moderately lower than the relative match-speeds of high-standard/high-fitness players in games 4 (ES = -0.65; Likelihood = 79%, Likely) and 5 (ES = -0.62; Likelihood = 76%, Likely). The internal loads across the tournament were greater in the high-standard/high-fitness group, with large differences in games 3 (ES = 1.23; Likelihood = 90%, Likely) and 4 (ES = 1.36; Likelihood = 94%, Likely).

There were very large correlations between session RPE and average total distance during the tournament in the high-standard/low-fitness (r = 0.924), in the low-standard/high-fitness (r = 0.965), and the low-fitness/low-standard group (r = 0.796), but only a small correlation in the high-standard/high-fitness group (r = 0.208). In contrast to their high-standard counterparts, low-standard players demonstrated gradual increases in playing intensity across each game of the competition (Figure 4.8A & Table 4.4). Low-standard/high-fitness players largely increased playing intensity through low-speed activity (ES = 0.41 to 1.42), and high-speed running (ES = 0.13 to 1.05), translating to gradual increases in relative match-speeds (ES = 0.30 to 1.22). Whilst low-standard/low-fitness players also showed increases in overall playing intensity (albeit smaller than the high-fitness players), across the competition (ES = 0.36 to 1.46), these were primarily brought about via increases in low-speed activity (ES = 0.09 to 0.89) and moderate-speed running (ES = 0.10 to 0.98). This was reflected in small to moderate increases in relative match-speed (ES = 0.34 to 1.19) as the tournament progressed. Both low-standard/high- and low-standard/low-fitness players had moderately lower relative match-speeds than the high-standard/high-fitness players in game 1 (ES = -1.05 and -1.03) and 2 (ES = -0.78 and -1.11). There was little difference in internal loads between fitness groups in the low-standard players (ES = 0.06 to 0.43). With regards to the frequency of collisions, there was little change across the competition for the majority of players (Figure 4.8B). However, there were moderate reductions in game 2 (ES = -0.72; Likelihood = 89%, Likely), 3 (ES = -0.77; Likelihood = 86%, Likely), and 5 (ES = -0.63; Likelihood = 74%, Possibly), in the high-standard/low-fitness players. There was also little change in RHIE bout frequency across the competition (Figure 4.8C), with only moderately greater frequency in game 4 for high-standard/high-fitness players (ES = -0.91 Likelihood = 60%, Possibly) and game 3 for low-standard/high-fitness players (ES = -0.91; Likelihood = 84%, Likely).

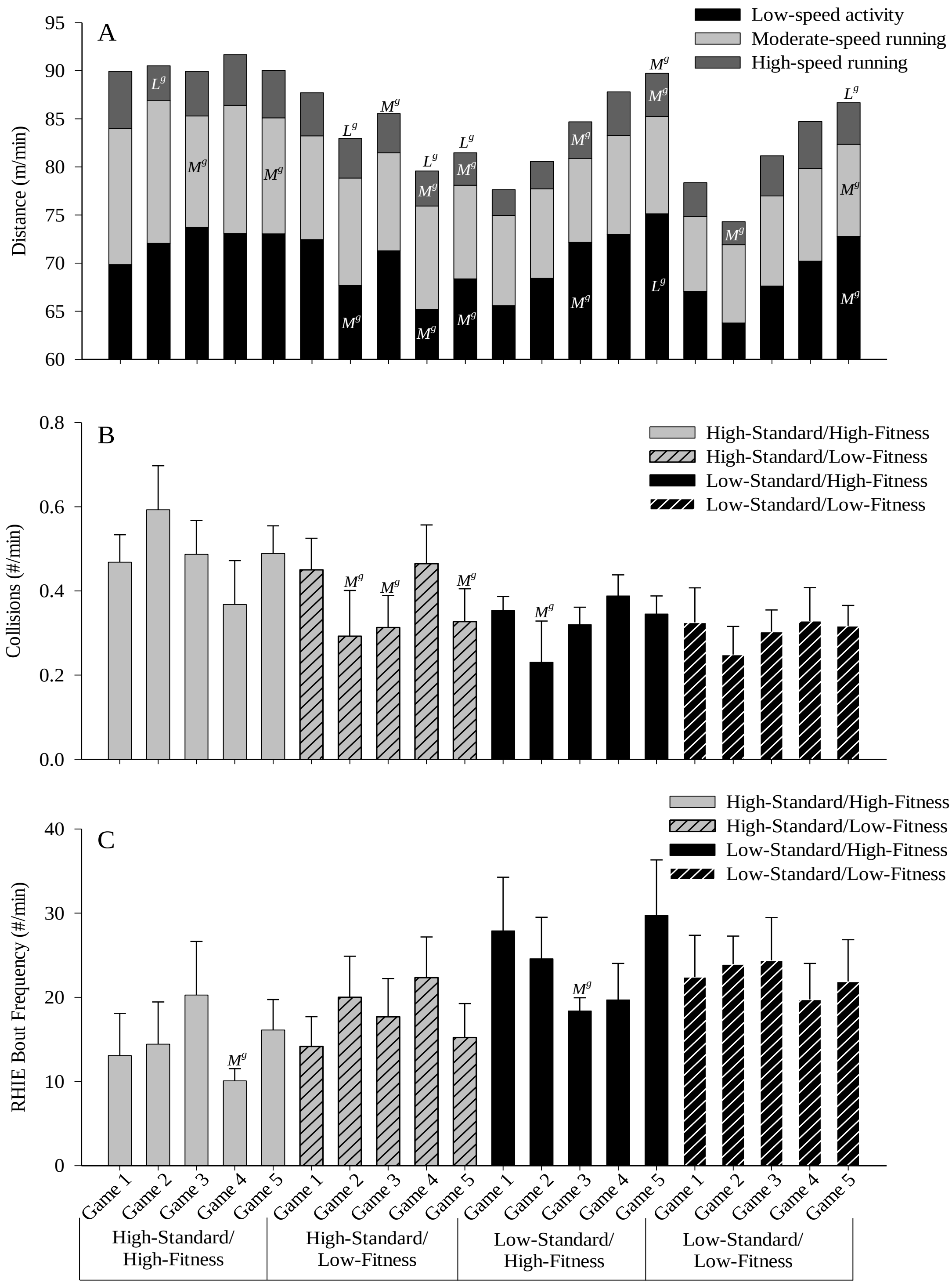

Figure 4.8. Changes in (A) relative distance, (B) collisions per minute, and (C) repeated high-intensity effort bout frequency during each game of the competition in the high-standard and low-standard players divided into high- and low-fitness groups. Data are presented as means ± SE. L^g denotes a large effect size difference (≥1.20) from Game 1; M^g denotes a moderate-effect size difference (0.61-1.19) from Game 1.

4.4.5 Discussion

The aim of this study was to assess pacing strategies used during a junior team sport tournament and establish whether these pacing strategies were influenced by playing standard and physical fitness. This study showed that high-standard players adopt an initially higher pacing strategy than their low-standard counterparts, which they can largely maintain across the competition before showing a slight reduction in the final game. This reduction in performance appears to be largely due to a decreased playing intensity in the low-fitness players, whereas the high-fitness players showed little reduction in playing intensity and a more even-paced strategy across the tournament. Conversely, low-standard players appear to utilise a slow-start or negative pacing strategy whereby they begin the competition with a low playing intensity, which gradually increases as the tournament progresses [13]. This pacing strategy is apparent in both low-standard fitness groups but is more pronounced in the high-fitness players. The results of this study demonstrate that well-developed fitness is related to a higher intensity pacing strategy and a better maintenance of playing intensity during periods of congested fixtures, such as tournaments.

The high-standard/high-fitness players were able to maintain overall playing intensity during each game of the tournament, suggesting an even-paced pacing strategy was used [13]. However, there were reductions in moderate- and high-speed running during some of the games, indicative of fatigue [85]. Despite this potential fatigue, high-standard/high-fitness players were able to increase low-speed activity during these games in order to maintain overall playing intensity. Moreover, they were able to maintain the frequency of RHIE bouts and physical collisions, which are known to be particularly fatiguing events [9, 20]. This may be due to the players being aware that performing RHIE bouts and tackles is central to the outcome of the game [25] and therefore prioritised energy towards the maintenance of these high-intensity efforts as opposed to running efforts. The high-standard/low-fitness players showed larger reductions in performance with moderate to large reductions in playing intensity in games 2-5, resembling an all-out or positive pacing strategy [13]. It is likely that the low-fitness players attempted to maintain a similar match-intensity to the high-fitness players early in the tournament but were unable to reproduce this intensity in subsequent games and therefore reduced match intensity as a self-preservation strategy in order to prevent catastrophic failure of any physiological system [12, 185]. These reductions in match intensity were initially brought about by reductions in low-speed activity, which may have been a conscious pacing strategy in an attempt to maintain important high-intensity actions [18, 19]. Despite this, in the final 2 games of the competition, low-fitness players demonstrated reductions in high-speed running, once again indicative of fatigue [85]. In addition, these low-fitness players demonstrated moderate reductions in the number of collisions during games 2, 3, and 5, which may have influenced the match outcomes [25]. This could be due to these players exhibiting greater fatigue responses due to poorly developed physical fitness which in turn results in greater reductions in activity profiles [139]. In addition, depleted muscle glycogen stores could also have contributed to the reduction in relative intensity and match-running profiles [12], although given the greater relative match-speeds across the high-fitness group, it is likely that substrate availability was similar between players. It appears that when low-fitness players are exposed to high-intensity match-play, they attempt to simply complete the game rather than make an impact by elevating their work rates.

Both the low- and high-fitness players from the low-standard group set a different pacing strategy to the high-standard players with an increase in overall playing intensity as the competition progressed, indicative of a slow-start or negative pacing strategy [13, 186]. They began the first game of the competition with a very low playing intensity in comparison to the high-standard group; by game 5, there was little difference in playing intensity between standards. This is reflected by lower relative speeds than the high-standard/high-fitness group in games 1 and 2 before similar relative speeds in the remaining games. Both high- and low-fitness players showed the same pacing strategy across the tournament, although, the increase in intensity was more pronounced in the high-fitness group. Low-fitness players increased playing intensity through elevations in low-speed activity and moderate-speed running, whereas the high-fitness group achieved this through increased low-speed activity and high-speed running. It is difficult to explain exactly why these players would adopt this particular pacing strategy, but it could be linked to their physical capabilities. Low-standard players, both high- and low-fitness, had poorer Yo-Yo IRT scores than their high-standard counterparts. As such, it could be that they originally set a low-intensity pacing strategy so they could complete the early games whilst conserving energy, allowing for increased work-rates in the later games on the competition rather than induce excessive fatigue which could lead to the failure of a single physiological system [13, 170]. There was little change in the RHIE and collision demands of each game, although they were less frequent than in the high-standard group, which is in accordance with previous research [60]. Taken together, players who have poorly developed physical fitness appear to adopt a slow-start pacing strategy where they can conserve energy early in the tournament in order to allow for increased work-rates as the competition progresses.

One interesting finding from this study was the association between session RPE and average total distance across the tournament. There were very large, positive correlations with each playing group and fitness levels, except in the high-standard/high-fitness group, suggesting a disconnect between perceived exertion and distance covered as physical fitness increased. Lovell et al., [88] previously reported strong correlations between total distance and RPE during rugby league training, but did not take into account physical fitness. Previous research has suggested that RPE increases as a scalar function of distance covered, [187] whilst this appeared to be the case for most of the fitness groups, it was not for the high-standard/high-fitness group. Given that RPE appears to closely control work rates during exercise, [12] this apparent disconnect in the high-standard/high-fitness players may explain why these players were able to maintain work rates across the competition. It may be that due to increased physical fitness, these players are able to tolerate a greater volume of work and discomfort without similar increases in perceived effort.

4.4.6 Conclusions

This is the first study to investigate the impact of physical fitness and playing standard on pacing strategies during a 4-day junior team sport tournament. The results of this study demonstrate that well-developed physical fitness allows for a higher pacing strategy that can be maintained throughout a tournament. High-standard players with poorly-developed physical fitness will initially reduce low-speed activities in an attempt to maintain high-intensity activity throughout the competition. However, this pacing strategy is insufficient and reductions in performance are seen during the latter stages of the competition. Low-standard players appear to adopt a pacing strategy that allows them to preserve energy in order to produce an 'end-spurt' towards the end of the competition. As such, coaching staff should aim to develop fitness across their entire playing group in order to maximise playing intensity and minimise performance reductions during the latter stages of a tournament. There are some limitations to the present study that warrant discussion. Firstly, the two teams in the study competed against different teams across each game of the competition. As such, contextual factors (e.g. possession, points scored) within each game could influence the findings of this study. Secondly, whilst we assessed between-game pacing strategies, within- game pacing was not assessed; this is an area for future research. Thirdly, whilst players within each side were provided food throughout the tournament by their respective management staff, there may have been some differences between the nutritional intakes of the high- and low-standard teams. Finally, the sample size of each group in this study was small and therefore the results may not be representative of the population. It is also important to note that whilst approximately 75% of the players had previously competed in this tournament there were some players who would not have been exposed to this previously, as such this may have influenced their ability to set an effective pacing strategy throughout the tournament. This study only assessed between-match pacing strategies; future research should aim to assess the influence of physical fitness on within-match or micro-pacing strategies. Despite these limitations, it is important to acknowledge the ecological validity of this study and the novelty of investigating the impact of physical fitness and playing standard on pacing strategies during congested fixtures.

4.4.7 Practical Applications

- Players with poorly developed physical fitness should be identified early in the season to allow sufficient time for these shortfalls to be addressed.
- The performance of a high-standard team can be compromised by sub-standard physical fitness in a select few players.
- Players with poor-physical fitness appear to preserve energy in order to be able to complete games through a tournament.

4.4.8 Acknowledgements

The authors would like to thank the players and staff from St Thomas More and Padua College for taking part in the study as well as the organising committee of the Confraternity Shield Carnival.

Chapter 5

Theme 2 – Post-match fatigue responses in rugby league players: causes and consequences

5.1 Study 5: Influence of an intensified competition on fatigue and match performance in junior rugby league players

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of an intensified competition on fatigue and match performance in junior rugby league players. *J Sci Med Sport*, 2013, 16: 460-5.

5.1.1 Abstract

The purpose of this study was to assess the physiological responses to an intensified rugby league competition and explore the relationships between fatigue and match performance. Prospective cohort experimental design was used. Fifteen junior rugby league players (n = 8 forwards, 7 backs; mean ± SE, age 16.6 ± 0.2 years; body mass 81.6 ± 3.0 kg; and height 178.9 ± 1.8 cm) competed in five 40 minute games over five days, (two games each on days 1 and 2, one game on day 4, and no games on days 3 and 5). Over the competition, players performed a countermovement jump to assess neuromuscular fatigue, provided a fingertip blood sample to measure blood creatine kinase, and completed a questionnaire to monitor perceived wellbeing; ratings of perceived effort were recorded following each game. Global positioning system and video analysis of each game were used to assess match performance. Over the first three days, there were progressive and large increases in neuromuscular fatigue which peaked 12 hr after game 4 (forwards ES = 4.45, p = 0.014; backs ES = 3.62, p = 0.029), and muscle damage which peaked 1 hr post game 4 (forwards ES = 4.45, p = 0.004; backs ES = 3.94 p = 0.012), as well as reductions in perceived wellbeing. These measures gradually recovered over the final two days of the competition. Compared to the backs, the forwards experienced greater increases in creatine kinase following game 2 (ES = 1.30) and game 4 (ES = 1.24) and reductions in perceived wellbeing (ES = 0.25-0.46). Match intensity, high-speed running, and repeated-high intensity effort bouts decreased in games 4 and 5 of the competition. Small to large associations were observed between the changes in fatigue, muscle damage and match performance, with significant correlations between creatine kinase and repeated high-intensity effort bout number (r = -0.70, p = 0.031) and frequency (r= 0.74, p = 0.002) and low-speed activity (r = -0.56, p = 0.029). Fatigue and muscle damage accumulate over an intensified competition, which is likely to contribute to reductions in high-intensity activities and work rates during competition.

5.1.2 Introduction

Senior rugby league matches result in significant muscle damage [27, 34, 36], neuromuscular fatigue [27, 34], and perceptual fatigue [27, 32]. While fatigue is generally transient in nature and typically persists for 24-48 hr after competition, muscle damage may last for several days [34]. During regular week-to-week matches, well-conditioned players are expected to recover in time for the next scheduled game [32]. However, there are times during the season when players are required to compete in intensified periods of competition where they are not afforded 5-10 days between matches. Intensified competition in junior players is particularly common as they are often required to compete in tournaments, or have simultaneous club, school, and representative commitments. Despite this, there is no information regarding the fatigue response to single games or tournaments in junior rugby league players. Research from junior basketball noted fatigue accumulated over a 3-day tournament which culminated in reductions in speed, agility, and vertical jump performance [29]. Furthermore, Rowsell et al., [37] reported reductions in high-speed running, total distance, and time spent in high heart rate zones in junior soccer players across a 4-day tournament. More specifically, research within senior rugby league players has shown that when there is only 48 hrs between matches, there are progressive reductions in neuromuscular function, perceptions of wellbeing and increases in markers of muscle damage [30]. Given the popularity of junior rugby league particularly in Australia and the United Kingdom, and the frequency of intensified competition, it is of interest to determine the physiological responses to an intensified period of competition within this population.

Few studies have examined the relationship between match performance and markers of fatigue. Research from Australian rules football suggests that residual fatigue prior to competition may compromise match performance [39, 188]. Furthermore, Johnston et al., [30] found match performance in senior rugby league players to be compromised in the presence of neuromuscular fatigue, muscle damage, and perceptual fatigue that followed intensified competition. They reported progressive reductions in neuromuscular function, perceived wellbeing, and increases in muscle damage as the tournament progressed. These increases in fatigue were coupled with reductions in high-intensity match activities in the final game of the competition. However, relationships between markers of fatigue and match performance were not assessed. The aims of the present study were to add to the fatigue-monitoring literature and extend the work of Johnston et al. [30] by (1) determining the physiological responses to an intensified period of junior rugby league competition, and (2) assessing the relationship between markers of fatigue and match performance in these players. It was hypothesised that fatigue would accumulate over the competition and be associated with reductions in match performance.

5.1.3 Methods

5.1.3.1 Design

To test our hypothesis, neuromuscular fatigue, muscle damage, and perceived wellbeing were monitored over the course of a junior rugby league tournament. Global positioning system (GPS) technology and video analysis were utilised to provide information on the activity profiles and match performance of players. Games were 40 min in duration (2 x 20 minute halves); with two games being played on both days 1 and 2 (11:00 and 15:00), no games on day 3, one game on day 4 (11:30), and no games on day 5, totalling 5 games over a 5 day period. The average temperature, rainfall, and humidity over the competition were 18.9 ± 0.7 °C, 11.7 ± 3 mm, and 15.3 ± 0.8%, respectively.

5.1.3.2 Subjects

Fifteen (backs, n = 7; forwards, n = 8) junior rugby league players (mean ± SE, age 16.6 ± 0.2 years; body mass 81.6 ± 3.0 kg; and height 178.9 ± 1.8 cm) from the same school 1st XIII participated in the study. The tournament took place in June, three months into the season. All players were free from injury at the time of testing. Players were asked to maintain their normal diet throughout the competition period; water was available *ad libitum* throughout the tournament. Before the study, players attended a familiarisation session and received an information sheet outlining experimental procedures, and the associated risks and benefits of participation; written informed consent was obtained from each player and their legal guardian. The study was approved by the ethical review board for human research.

5.1.3.3 Protocol

Over the course of the five day tournament, each player competed in five 40 minute games with games 1 and 2, and 3 and 4 each separated by approximately 3 hrs. Baseline measurements of neuromuscular fatigue, muscle damage, and perceived wellbeing were assessed approximately 1 hr prior to each game and within 1 hr of the players finishing each match. Data collected post-game 1 and 3 were used as pre-game measures for games 2 and 4 respectively.

5.1.3.4 Markers of Fatigue

Neuromuscular fatigue was assessed using peak power from a countermovement jump (CMJ) on a force platform (Kistler 9290AD Force Platform, Kistler, USA) connected to a laptop (Acer Aspire 2930, Acer, UK) and using software provided by the manufacturer (QuattroJump, Kistler, USA). Following a standardised warm-up comprised of dynamic stretching and two practice jumps, players performed one CMJ on the platform. Players were instructed to keep their hands on hips, and jump as high as possible; no instructions were given as to the depth of the countermovement [30].

Whole-blood creatine kinase (CK) activity was used as a marker of muscle damage. After pre-warming of a hand to approximately 42˚C via immersion in warm water, a 30 µl sample of blood was taken from a fingertip and immediately analysed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, the instrument was calibrated in accordance with the manufacturer recommendations. The “normal” reference range for CK activity, as provided by the manufacturer using this method, is 24–195 $IU \cdot l^{-1}$ [27, 30, 189]. The typical error of measurement (TE) expressed as a coefficient of variation for CK was 3.3%.

Each morning, perceived wellbeing was assessed by the experimenter asking players to rate feelings of fatigue, muscle soreness, sleep quality, mood and stress on 0-5 Likert scales, with the individual scores summated to give an overall wellbeing score using methods outlined previously [30]. Additionally, 30 min after each game, rating of perceived exertion (RPE) was recorded using a modified RPE scale to rate how hard players perceived each game. The RPE score was then multiplied by the number of min played to determine session load [172].

5.1.3.5 Match Activities

Match performance was assessed by GPS and video analysis. Prior to the warm-up before each game, players were fitted with the GPS vest and unit; the unit was switched on, and inserted into a padded compartment at the rear of the vest, positioned between the shoulder blades. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included 100 Hz tri-axial accelerometers, gyroscopes, and magnetometers to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and analysed using software provided by the manufacturer (Sprint, Version 5, Catapult Sports, VIC, Australia). Non-playing minutes were omitted from the analysis. Data were categorised into low (0-5 $m \cdot s^{-1}$) and high speed ($\geq$5.1 $m \cdot s^{-1}$) movement bands; the number and nature of collisions were categorised as described previously [2]. Repeated high-intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration ($\geq$2.78 $m \cdot s^{-2}$), high-speed, or impact efforts with less than 21 s between each effort [2]. These units are reliable for quantifying movements commonplace in rugby league [160, 164, 166].

In addition to GPS analysis, each game was filmed (Cannon Legria HV40, Japan) from an elevated position on the halfway line. The zoom function of the camera was set so that there was a field of view of approximately 10 m around the ball at all times. The games were analysed for completed tackles (TE = 6.4%), missed tackles (TE = 7.0%), ineffective tackles (TE = 11.4%) and successful tackles (TE = 7.9%) using methods described previously [10, 30]. The reliability was determined by the operator coding one game on two occasions separated by one month.

5.1.3.6 Statistical Analyses

Data were analysed using SPSS 19.0 (SPSS Inc, Chicago, IL, USA); changes in CK, neuromuscular fatigue, and perceived wellness between forwards and backs were compared using a two-way (group x time) repeated measures ANOVA. If significant main effects were found, Bonferroni *post hoc* analyses were performed to locate the differences. The magnitude of change in the dependent variables, including changes in match performance were also assessed using Cohen's effect size (ES) statistic [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Pearson's correlation coefficient was used to assess the relationship between the dependent variables. Correlations of 0.10-0.29, 0.30-0.50, 0.51-0.70, and ≥0.71 were considered small, moderate, large and very large respectively [176]. The TE was used to determine the test re-test reliability of the dependent variables. Data are reported as means ± standard error (SE) or 95% confidence intervals (CI); significance was set at $p<0.05$. Based on an alpha level of 0.05 and a sample size of 15, our type I and type II error rates were 5% and 20% respectively [190].

5.1.4 Results

Large ($p<0.05$, ES = 1.97 to 4.45) increases in CK were observed at each time point throughout the competition in the forwards (Figure 5.1A). The backs, showed significant increases in CK at 1 hr post-game 2, 1 hr pre-game 3, and 1 hr post-game 4; at every other time point, there were large, but non-significant increases in CK ($p>0.05$; ES = 1.38 to 3.62). Furthermore, compared with the backs, there were large differences in CK following game 2 (ES = 1.30) and game 4 (ES = 1.24) in the forwards. In both positional groups, CK peaked at 1 hr post-game 4 (forwards ES = 4.45; backs ES = 3.94) before a gradual recovery. Despite this, CK remained above baseline values by day 5 of the competition in both the forwards ($p = 0.01$; ES = 1.97) and the backs ($p = 0.41$; ES = 1.38).

There was no difference in the progressive reductions in CMJ peak power between the forwards and backs up until 12 hr post-game 4, with significant reductions ($p<0.05$) 1 hr post-game 3, 1 hr post-game 4, 12 hr post-game 4, and 1 hr pre-game 5 (Figure 5.1B). After 12 hr post-game 4, there was a gradual recovery in neuromuscular function; by 24 hr post game 5, neuromuscular function had returned to baseline. There were no changes in peak force over the competition in forwards or backs.

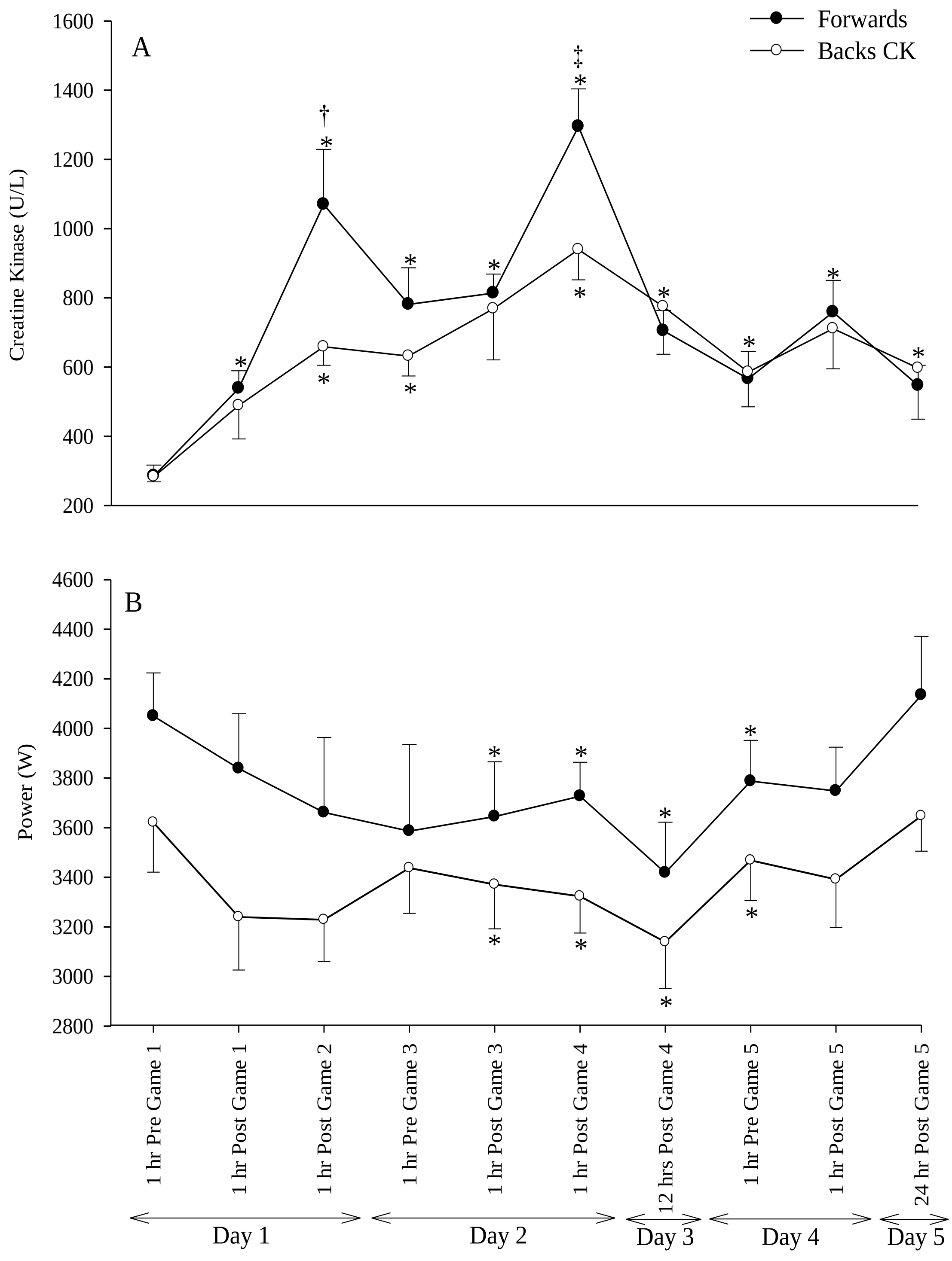

Figure 5.1. Mean (± SE) creatine kinase (A) and peak power for the countermovement jump (B) for forwards and backs over the 5 day competition. * Denotes significantly different to pre-game 1; † denotes significantly different to post-game 1; ‡ denotes significantly different

to post-game 3 ($p < 0.05$). No significant ($p>0.05$) group x time interactions were observed. There were as few as 3 hours between games 1 and 2, and 3 and 4, as much as 36 hours between games 4 and 5.

Significant reductions in perceived wellbeing (Figure 5.2) were observed in the forwards on day 2 (p=0.02; ES = -1.80), day 3 (p=0.02; ES = -1.33) and day 4 (p=0.05; ES = -1.07). There were non-significant, but meaningful reductions in perceived wellbeing in the backs on each morning of the competition when compared to baseline (p>0.05; ES = -1.11 to -3.99). By day 5, perceived wellbeing had returned to baseline in both groups. Compared to the backs, the forwards experienced greater reductions in perceived wellbeing on each day of the competition, with small effect size differences (ES = 0.25-0.46). There was no change in RPE load across each game of the competition (p>0.05; ES = 0.12-0.43).

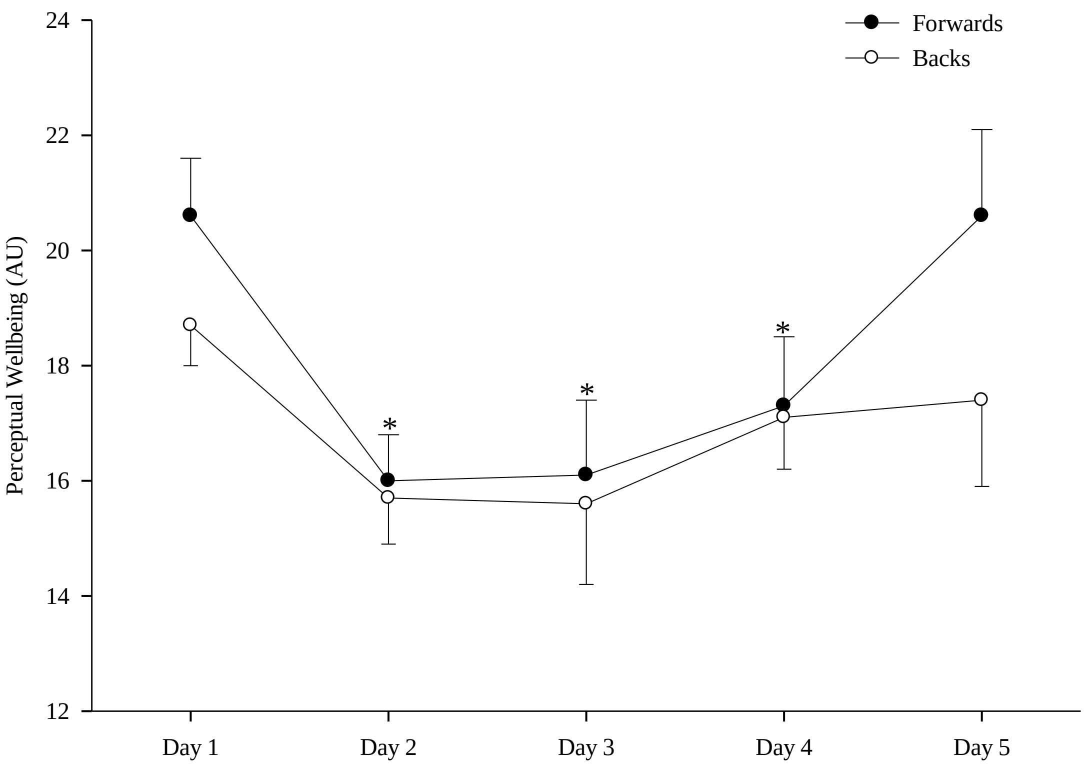

Figure 5.2. Mean (± SE) perceptual wellbeing for forwards and backs for each morning of the 5 day competition. * Denotes significantly different to Day 1 ($p < 0.05$). No significant ($p>0.05$) group x time interactions were observed.

There were moderate to large reductions in relative distance, low-speed activity, high-speed running and RHIE bout frequency in games 4 and 5 compared to game 1 in both the forwards and the backs (Table 5.1). In addition, there were moderate reductions in the number and frequency of collisions in game 4, and frequency in game 5 in the forwards. On average, across the competition, the forwards performed a greater number (ES = 1.20) and frequency (ES = 1.40) of collisions, and number (ES = 1.34) and frequency (ES = 2.43) of RHIE bouts compared with the backs. The backs performed more relative high-speed running (ES = 0.67) over the competition compared with the forwards (Table 5.1). Over the course of the competition, the team won 2 games, and lost 3, scoring 70 points, and conceding 64. They won game 1 and 5, and lost games 2, 3, and 4.

Table 5.1. Performance variables for forwards and backs for each game of the competition. †

		Game 1	Game 2	Game 3	Game 4	Game 5
Playing time (min)	F	26.2 (16.8-35.4)	26.9 (14.7-39.1)	28.1 (15.8-40.4)	32.1 (23.5-40.8)	26.4 (17.4-35.3)
	B	25.2 (16.0-34.0)	25.6 (16.4-34.9)	28.3 (18.7-33.9)	24.9 (18.2-31.7)	25.1 (18.2-31.9)
Distance covered (m)	F	2632 (2000-3264)	3113 (2609-3616)	3042 (2630-3453)	2370 (1636-3104)	2302 (1926-2677)
	B	2306 (1133-3145)	2132 (1362-2901)	2387 (1663-3112)	1905 (1443-2367)	2046 (1518-2574)
Relative distance ($m \cdot min^{-1}$)	F	90 (85-94)	83 (77-85)	81 (73-89)	73 (66-79) *L*[1]	78 (72-84) *L*[1]
	B	82 (76-90)	82 (78-87)	87 (79-93)	75 (68-82) *M*[2]	74 (72-76) *L*[1]
Low-speed running (m)	F	2484 (1884-3084)	2981 (2507-3454)	2857 (2452-3261)	2280 (1572-2989)	2210 (1872-2548)
	B	2155 (1353-2957)	2027 (1264-2790)	2185 (1502-2868)	1825 (1373-2276)	1977 (1471-2482)
Low-speed running ($m \cdot min^{-1}$)	F	85 (80-89)	79 (74-85)	76 (68-85)	70 (63-76) *L*[1]	75 (68-81) *L*[1]
	B	77 (70-84)	78 (74-82)	78 (73-83)	71 (66-77) *M*[2]	71 (70-73) *M*[2]
High-speed running (m)	F	126 (83-169)	120 (68-172)	169 (123-214)	89 (63-116) *M*[2]	90 (33-146)
	B	138 (94-182)	89 (59-118)	145 (108-183)	66 (148-85) *L*[1]	61 (34-88) *L*[1]
High-speed running ($m \cdot min^{-1}$)	F	4 (3-5)	3 (2-4)	5 (3-6)	2 (2-3) *L*[1]	3 (1-4) *M*[2]
	B	6 (4-7)	4 (3-5)	6 (4-7)	3 (2-4) *L*[1]	2 (1-3) *L*[1]
Collisions						
Total (no.)	F	20 (12-28)	29 (21-31)	23 (17-29)	14 (8-19) *M*[2]	15 (9-21)
	B	9 (5-13)	10 (3-16)	12 (4-21)	9 (3-15)	7 (3-11)
Total (no./min)	F	0.68 (0.52-0.84)	0.68 (0.62-0.75)	0.62 (0.48-0.76)	0.46 (0.35-0.58) *M*[2]	0.45 (0.30-0.60) *M*[2]
	B	0.28 (0.19-0.37)	0.33 (0.19-0.46)	0.60 (0.37-0.83)	0.31 (0.17-0.46)	0.22 (0.13-0.32)
RHIE						
Bouts (no.)	F	3 (0-5)	4 (3-5)	3 (2-4)	2 (0-3)	1 (0-2)
	B	1 (1-2)	1 (1-2)	1 (1-2)	0 (0-1) *M*[2]	0 (0-1) *M*[2]
Bout frequency ($no \cdot min^{-1}$)	F	1 every 24 min	1 every 10 min	1 every 16 min	1 every 28 min *L*[1]	1 every 32 min *L*[1]
	B	1 every 31 min	1 every 29 min	1 every 26 min	1 every 37 min *M*[2]	1 every 36 min *M*[2]

Table 5.1. Continued

		Game 1	Game 2	Game 3	Game 4	Game 5
Match Statistics						
Missed tackles (no.)	F	0.14 (-0.12-0.4)	0.71 (0.19-1.24)	0.57 (0.03-1.12)	0.75 (0.14-1.36)	0.38 (0.02-0.73)
	B	0.00 (0.00-0.40)	0.29 (-0.08-1.24)	0.14 (-0.14-1.12)	0.29 (-0.08-1.36)	0.00 (0.00-0.73)
Successful tackles (%)	F	87 (82-92)	84 (71-97)	72 (61-84)	76 (67-84)	81 (70-91)
	B	92 (82-101)	72 (58-86)	70 (53-87)	73 (60-86)	94 (85-104)

† Data are presented as means (95% Confidence Intervals) for forwards (F) and backs (B). Low-speed activity represents movements <5 $m \cdot s^{-1}$; High-speed running represents movements >5.1 $m \cdot s^{-1}$. A repeated high-intensity effort (RHIE) bout was classified as 3 or more maximal accelerations, high-speed, or impact efforts with less than 21 s between each effort. L^1 Denotes large effect size difference (≥1.20) to game 1; M^2 denotes a moderate effect size difference (0.61-1.19) to game 2.

Table 5.2. Relationship between the change in fatigue markers and the change in performance variables across the tournament. †

	Relative Distance	LSA	HSR	RHIE Bouts	RHIE Bout Recovery Time	Successful Tackles
Peak Power	0.32	0.32	0.44	0.45	-0.06	0.16
Creatine Kinase	-0.49	-0.56*	-0.09	-0.70*	0.74*	-0.18
Perceived Wellbeing	0.13	0.31	0.31	0.50	-0.35	0.33

† Data are reported as Pearson product moment correlations (r), with 0.11-0.3 = small; 0.31-0.5 = moderate; 0.51-0.7 = large; ≥0.71 = very large. LSA = Low-speed activity; HSR = High- speed running; RHIE Bout = Repeated high-intensity effort bout. * Denotes a significant correlation (p<0.05).

There were small to moderate associations (Table 5.2) between changes in neuromuscular fatigue, muscle damage and perceptions of wellbeing and match performance variables. Increases in CK were significantly associated with an increase in RHIE bout recovery time ($r = 0.74$; $p=0.002$), reductions in the number of RHIE bouts ($r = -0.70$; $p=0.03$), reductions in low-speed activity ($r = -0.56$; $p=0.03$), and a greater number of total collisions ($r = 0.62$; $p=0.01$).

5.1.5 Discussion

This study investigated the physiological responses to an intensified rugby league competition (5 games over 4 days) and assessed the relationships between fatigue and match performance in junior players. There were progressive increases in muscle damage and neuromuscular fatigue as well as reductions in perceptual wellbeing over the first 3 days of the competition before a gradual recovery in these measures. Changes in muscle damage and perceptual wellbeing were greater in the forwards compared to the backs. Relative distance covered, high-speed running, low-speed activity and RHIE bouts were attenuated in the final two games of the competition. In general, there were small to moderate relationships between markers of fatigue and match performance, although a large, positive relationship was found between increases in CK and RHIE bout recovery. These results indicate that markers of fatigue accumulate over an intensified competition, and are exacerbated within the forwards. Moreover, increases in fatigue contributed to reductions in match performance in witnessed across the competition.

There were progressive reductions in neuromuscular function and perceptual wellbeing, as well as increases in muscle damage in both forwards and backs over the first 3 days of the competition before a gradual recovery. Neuromuscular fatigue and perceived wellbeing returned to baseline by day 5; CK was still elevated on day 5 in both groups. Changes in neuromuscular function were highlighted by decreases in peak power, which confirms previous findings from intensified rugby league competition [30]. The increases in neuromuscular fatigue were similar between backs and forwards, which supports the findings of Twist et al. [27]. The reduction in power and maintenance in force output suggests that there is preferential disruption to type II muscle fibres during rugby league competition, resulting in a change in the force-velocity relationship towards slower muscle [191]. As such, high-velocity movements should be avoided in the 24-48 hr after competition.

Greater increases in muscle damage were observed in the forwards compared with the backs. The greater peaks in CK experienced by the forwards after games 2 and 4 may be explained by the greater number and frequency of collisions in which these players were exposed during the competition. Indeed, collisions were significantly correlated with increases in CK over the tournament, lending further support to the hypothesis that physical impacts are a major contributor to the muscle damage response following rugby league games [27, 36]. In addition, the greater number and frequency of RHIE bouts performed by the forwards may also have accentuated the fatigue response. Previous research has found repeated-effort activity to be associated with greater physiological cost and perceived effort than repeated-sprints alone [9]. With this in mind, the greater frequency of collisions and RHIE bouts performed by the forwards could explain the greater increases in muscle damage.

The reductions in perceived wellbeing over the first 3 days of the competition in both positional groups, supports previous studies that found disturbed psychological states after intensified training and competition [30, 192, 193]. Moreover, it highlights the utility of simple, cost-effective questionnaires for monitoring a player's perceived recovery status following competition. The greater reductions in perceived wellbeing in forwards compared to backs is in accordance with others [27]. This disparity may be related to the larger muscle damage response in the forwards which resulted in greater perceptions of fatigue and muscle soreness. Collectively, these data highlight that the fatigue response to intensified competition is different between forwards and backs, which is likely due to contrasting match activities (Table 5.1). With this in mind, training and recovery practices for forwards and backs should differ in the days following competition to allow for the increased fatigue in the forwards to dissipate.

In the present study, a number of match performance variables were attenuated in the final two games of the competition. There were meaningful reductions in relative distance, high-speed running, low-speed activity, and RHIE bouts in games 4 and 5 of the competition. These reductions in performance are in accordance with previous studies of intensified rugby league [150], and field hockey [194] competition, which may have ramifications on match outcome. Indeed, research from rugby league competition suggests that winning teams maintain higher match intensities, and cover greater distances at low speeds compared with their less successful counterparts [55]. Furthermore, RHIE bouts have been reported to occur in close proximity to points scored or conceded [76]. As such, a reduction in these variables may prove vital in the outcome of a match.

The reductions in performance variables is partially explained by the cumulative fatigue, with moderate to large associations observed between increases in fatigue and reductions in a number of performance variables (Table 5.2). Increases in CK were significantly associated with the reductions in low-speed activity and frequency of RHIE bouts, whereas changes in power and wellbeing shared moderate associations with these variables. The relationships between CK and performance suggest that muscle damage may contribute to a reduction in the ability to maintain match intensity and perform high-intensity efforts. The reductions in power may also help explain some of the reductions in the number of RHIE bouts performed. High power outputs in rugby league players are positively associated with sprint performance [115], therefore, reductions in power could have prevented players performing high-intensity activities. The relationships between perceptual wellbeing and performance variables suggest that increases in perceived muscle soreness and fatigue stimulated reductions in central drive which resulted in reductions in work rates [193, 195]. Indeed, due to the demanding nature of RHIE bouts [9], during the latter games, players may not have had the physiological or psychological capacity to perform these bouts. While significant correlations do not imply cause and effect, our findings suggest that fatigue contributed to reductions in match performance, and that players need to be free from fatigue prior to competition. Moreover, there is not one single fatigue marker that can account for the reductions in performance. As such, a combination of monitoring tools is required in order to determine a player's readiness to train and compete.

5.1.6 Conclusions

These findings show that there are progressive increases in markers of fatigue during an intensified junior rugby league competition. Forwards experienced greater increases in CK and reductions in perceived wellbeing compared with backs. The greater changes may be due to a greater number of physical collisions and RHIE bouts which resulted in greater tissue damage, and disturbed psychological states. There were meaningful reductions in important match activities in the final games of the competition. Fatigue and muscle damage partially explain these reductions in match performance in the latter stages of an intensified competition. Given the large between-match variation in performance, which could have been influenced by environmental conditions, quality of the opposition, team selection and the referee, further research investigating the influence of fatigue on match performance under more controlled conditions such as a simulation protocol would provide a better understanding into the influence residual fatigue has on match performance. In addition, exploring methods for reducing the fatigue response following competition (e.g. through nutritional, pharmacological, or massage manipulations) is also warranted in order to help maintain subsequent performance.

5.1.7 Practical Applications

- Residual fatigue prior to competition contributes to reductions in high-intensity match activities. Players should be free from fatigue prior to competition.
- High-velocity movements should be avoided in the 24-48 hrs following competition.
- A combination of monitoring tools, such as countermovement jumps and perceptual wellbeing questionnaires should be utilised to determine a player's readiness to train and compete.
- Forwards experience more fatigue following intensified competition compared with backs which may be due to an increased exposure to collisions and RHIE bouts.

5.1.8 Acknowledgements

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5.2 Study 6: Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games

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5.2.1 Abstract

Physical contact is frequent in rugby league competition and is thought to be a major contributor to the fatigue and creatine kinase (CK) response, although direct evidence is lacking. The aim of this study was to investigate the influence that physical contact had on the fatigue and CK response to small-sided games. A cross-over, counter-balanced design was used. Twenty-three junior elite rugby league players were divided into two groups. Group one played a contact game on day 1 before playing a non-contact game 72 hours later; group two played the games in reverse order. The rules were identical for each game, with the only difference being a 10 second contact bout every 50 seconds during the contact game. Upper and lower body neuromuscular fatigue and blood concentrations of CK were assessed immediately before, immediately after, and 12 and 24 hours after the games. During each game, players wore global positioning system units to provide information on movements. CK increased after both games, peaking immediately following the non-contact game; CK was still rising 24 hours following the contact game. The difference between the two conditions was practically meaningful at this point (likelihood = likely, 82%; ES = 0.86). There were moderate to large reductions in upper body power following the contact game (ES = -0.74 - -1.86), and no reductions following the non-contact game. This study indicates that large increases in blood CK and upper body fatigue result from physical contact. Training sessions involving physical contact should be performed well in advance of scheduled games.

5.2.2 Introduction

Rugby league is a contact sport with periods of high- and low intensity activity [2, 8]. During competition, players typically cover distances of 90-100 $m \cdot min^{-1}$ [2, 5, 8], including 6-14 $m \cdot min^{-1}$ at high-speeds [2, 8]. In addition, to these running demands, players frequently engage in physical collisions during attack and defence. Players perform 24-47 contact efforts during a game or 0.38-1.09 per minute depending on position [10].

Due to the demanding nature of rugby league, players experience considerable fatigue and increases of myofibre proteins within the blood, indicative of muscle damage [196], following competition [27, 32, 34]. Physical collisions encountered during competition are thought to be a major contributor to this fatigue. Indeed, research from rugby league has reported positive relationships between the number of collisions performed during competition and increases in creatine kinase activity (CK), and lower body neuromuscular fatigue [27, 33, 36]. It is thought that the blunt force trauma associated with physical collisions results in skeletal muscle damage and reduced muscle function. In addition, one study has reported decrements in upper body neuromuscular function following rugby league competition [30]. The authors suggested that physical collisions may have been responsible for the increases in upper body fatigue, but this was not determined. Although these studies provide an insight into the potential role collisions play in the fatigue and muscle damage response, they do not show cause and effect.

Direct evidence supporting the relationships between physical contact, fatigue and muscle damage is far from substantive. Performing tackles in combination with repeated-sprints results in a greater heart rate and perceived effort than performing repeated sprints alone; however, whether there is any difference in the fatigue response following such activity is unclear [9]. Previous studies have assessed the impact of contact on fatigue following team sport simulation protocols, but failed to see any increase in markers of muscle damage in the form of blood CK [197, 198]. Although controlled, the contact used in both these studies did not reflect the demanding nature or frequency of competition contact efforts [5]. As such, further evidence is required within a controlled environment utilising contact similar to that of competition to determine the impact collisions have on markers of fatigue and muscle damage.

Small-sided games (SSG) are regularly used in rugby league training in an attempt to replicate the demands of competition, providing players with a specific training stimulus and the opportunity to test skills under pressure and fatigue. Recent studies have shown that these games can elicit similar movement and skill demands [199, 200], as well as physiological responses seen during competition [201], which directly translate into improvements in fitness and match performance [202, 203]. These games can be either played with or without contact [200], and therefore present a semi-controlled, yet ecologically valid platform to assess the influence of physical contact on fatigue and muscle damage following small-sided games. Therefore, the aim of this study was to assess the influence of physical contact on the fatigue and muscle damage response to SSG. Based on the current literature it was hypothesised that the addition of contact to SSG would result in greater upper body fatigue and muscle damage compared to SSG without contact.

5.2.3 Methods

5.2.3.1 Design

A crossover, counterbalanced design was used. Neuromuscular fatigue, blood CK (an indirect marker of muscle damage), and perceived wellbeing were monitored before, immediately after, 12, and 24 hours following 'offside' SSG with and without contact. Global positioning system (GPS) microtechnology devices were used to assess movements during the small-sided games. Players were randomly divided into two groups; one group played the small-sided game with no contact first followed by the small-sided game with contact 72 hours later; the second group played the games in reverse order.

5.2.3.2 Subjects

Twenty-three elite junior rugby league players (age 19.1 ± 0.8 years; height 178.3 ± 22.9 cm; body mass 93.7 ± 9.2 kg) from the same National Rugby League club participated in the study. One extra player participated in the games only (i.e. no fatigue or CK measurements) in order to equalise player numbers. Data were collected in the penultimate week of pre-season, with players free from injury and in peak physical fitness. Before the study, players received an information sheet outlining experimental procedures; written informed consent was obtained from each player. Over the course of the testing period, players were asked to maintain their normal diet. The study was approved by the University's ethical review board for human research.

5.2.3.3 Protocol

Two SSG were performed in two training sessions separated by 72 hours. Both games were 'offside' small-sided games, one with contact, and one without contact, regularly used by the coaches during training. Players were divided into 4 teams (each of 6 players); teams 1 and 2 played the non-contact game first and then the contact game 72 hours later; teams 3 and 4 played the games in reverse order. Each game consisted of two 8 minute halves separated by a 90 second rest interval played on a grass training pitch in a standardised (30 x 70 m) playing area. The 'offside' game permitted each team to have three 'plays' whilst in possession of the ball. A 'play' ended when the player in possession of the ball was touched by a defender with two hands. The ball was turned over when the attacking side had completed three 'plays'. Unlike a regular small-sided rugby game, during the 'offside' game, the ball can be passed in any direction (i.e. to 'offside' players). The only difference between the two games was the addition of 8 x 10 second contact and wrestle periods during each half of the contact game. The players were asked to perform alternate shoulder pummels for 5 seconds, before being given 5 seconds to wrestle their partner onto their back. All players received coaching on wrestling techniques as part of their training and were familiar with this contact drill. Simulated contacts similar to those used in the present study have been shown to have good reproducibility in rugby league players.[9] After each contact period, the game resumed. Other than the 16 contact periods, there was no difference in the rules, verbal encouragement, pitch size, player number, and match duration between the contact and non-contact game.

5.2.3.4 Markers of Fatigue

Neuromuscular fatigue was assessed immediately before, immediately after, 12, and 24 hours following each game. Lower body neuromuscular fatigue was assessed using a countermovement jump (CMJ); upper body neuromuscular fatigue was assessed using a plyometric push-up (PP), both of which are described previously [30]. Both exercises were performed on a force platform (Kistler 9290AD Force Platform, Kistler, USA) connected to a laptop (Acer Aspire 2930, Acer, UK) running manufacturer designed software (QuattroJump, Kistler, USA). Peak power and force were the dependant variables, and calculated as defined previously [151]. Previous research has reported typical error of measurement (TE) for CMJ peak power and peak force as 2.9% and 2.2% respectively [151]. The TE for the PP was 5.0% and 2.4% for peak power and peak force, respectively.

Whole blood CK was assessed at the same time points as neuromuscular fatigue as an indirect marker of muscle damage. After pre-warming of the hand, a 30 μl sample of blood was taken from a fingertip and analysed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, the instrument was calibrated in accordance with the manufacturer recommendations [27, 30]. The TE for CK was 3.3%.

Perceptual wellbeing was assessed in the first fatigue monitoring session of each day. This was assessed by the experimenter asking players to rate feelings of fatigue, muscle soreness, sleep quality, mood and stress on 0-5 Likert scales; the individual scores were summated to give an overall wellbeing score [30]. In addition, 30 min after each game, rating of perceived exertion (RPE) was recorded using the CR-10 RPE scale to rate how hard players perceived each game. Session RPE has been found to be a valid method of assessing internal load in rugby league players [88].

5.2.3.5 Match Activities

Game movements were assessed by GPS microtechnology devices fitted between the shoulder blades of the manufacturer-provided vest. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included 100 Hz tri-axial accelerometers, gyroscopes, and magnetometers to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and subsequently analysed (Sprint, Version 5, Catapult Sports, VIC, Australia). Data were categorised into low (0-5 $m \cdot s^{-1}$) and high speed (≥5.1 $m \cdot s^{-1}$) movement bands. Repeated high-intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration (≥2.78 $m \cdot s^{-2}$), high-speed, or contact efforts with less than 21 s between each effort.[2] These units have been shown to offer a valid and reliable method of quantifying movements that are commonplace in rugby league [160, 164, 166].

5.2.3.6 Statistical Analyses

The differences in fatigue, muscle damage and running demands between the contact and non-contact games and changes over time were determined using traditional null hypothesis significance testing, and magnitude based inferences. In order to determine changes in neuromuscular function and blood CK, a two-way (condition x time) repeated measures ANOVA was used to determine the statistical significance of any differences. To compare differences in activity profiles between the contact and non-contact games, paired-samples t-test were used with a Bonferroni adjustment. These statistical tests were conducted using SPSS version 19 (SPSS for Windows, IBM Software, NY, USA). Based on the real-world relevance of the results, two statistical methods were used to determine the meaningfulness of any differences. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x the between subject standard deviation. Thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; >99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± 95% confidence intervals (CI); the significance level was set at $p<0.05$.

5.2.4 Results

The running loads of the contact and non-contact SSG are shown in Table 5.3. The running loads were greater in the non-contact game compared with the contact game for total distance ($p = 0.001$; likelihood = almost certain, 100%; ES = 2.48 ± 1.14), relative distance ($p = 0.001$; likelihood = almost certain, 100%; ES = 2.45 ± 1.09), high-speed distance ($p = 0.003$; likelihood = very likely, 95%; ES = 0.78 ± 1.05), and low speed distance ($p = 0.001$; likelihood = almost certain, 100%; ES = 2.18 ± 1.04).

Table 5.3. Physical demands of the contact and non-contact small-sided games. †

	Contact	Non-Contact	Difference (%)	ES	Likelihood	Descriptor
Distance (m)	1862 (1772-1880)*	2240 (2160-2319)	18 (17-20)	2.48 (1.42-3.62)	100%	Almost Certain
Relative distance ($m \cdot min^{-1}$)	114 (111-118)*	140 (135-145)	18 (17-20)	2.45 (1.34-3.54)	100%	Almost Certain
High-speed running (m)	224 (196-251)*	283 (242-324)	21 (10-32)	0.78 (-0.19-1.83)	95%	Very Likely
High-speed running ($m \cdot min^{-1}$)	14 (12-16)*	19 (16-22)	21 (10-32)	0.78 (-0.19-1.83)	95%	Very Likely
Low-speed activity (m)	1588 (1531-1645)*	1936 (1862-2001)	18(16-20)	2.18 (1.14-3.22)	100%	Almost Certain
Low-speed activity ($m \cdot min^{-1}$)	100 (96-102)*	121 (116-126)	18 (16-20)	2.18 (1.14-3.22)	100%	Almost Certain
RHIE Bouts (no.)	1.0 (0.1-2)	0.3 (0.1-0.5)	18 (1-35)	0.39 (-0.55-1.44)	26%	Possibly

† Data are reported as means ± 95% confidence intervals. Low-speed activity refers to movements $<5\ m \cdot s^{-1}$; high-speed running refers to movements $\geq 5.1\ m \cdot s^{-1}$; RHIE Bout = repeated high-intensity effort bout, 3 or more maximal acceleration, high speed or contact efforts with ≤21 seconds between each effort. ES = Effect size difference; effect sizes of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate, and large, respectively. Descriptor refers to the chance that the difference between the contact and non-contact games is practically meaningful. * Denotes $p < 0.05$ between the contact and non-contact games.

There was a significant main effect of time ($F_{1,45}$ = 6.08, p = 0.004, η_p^2 = 0.253) and game ($F_{1,45}$ = 7.14, p = 0.016, η_p^2 = 0.284) on blood CK (Figure 5.3). Compared with baseline values (contact = 699.4 ± 147.4 U/L; non-contact = 759.4 ± 137.9 U/L), moderate and large increases in CK were observed immediately after the contact (ES = 1.09 ± 1.0) and non-contact (ES = 1.27 ± 1.0) games (Figure 5.3). There was a decrease in CK at 12 hours (ES = 0.78 ± 1.0) and 24 hours (ES = 0.95 ± 1.0) after the non-contact game. However, following the contact game, there were further increases in CK at 12 (ES = 1.25 ± 0.93) and 24 hours (ES = 1.64 ± 0.94) post game. There were small differences between the contact and non-contact games immediately (likelihood = possibly, 59%; ES = 0.25 ± 0.78), and 12 hours following the games (likelihood = possibly, 69%; ES = 0.38 ± 0.98). At 24 hours post game, there was a moderately greater, and practically meaningful increase in CK following the contact game (54 ± 32%) compared with the non-contact game (22 ± 13%) (likelihood = likely, 82%; ES = 0.86 ± 1.0).

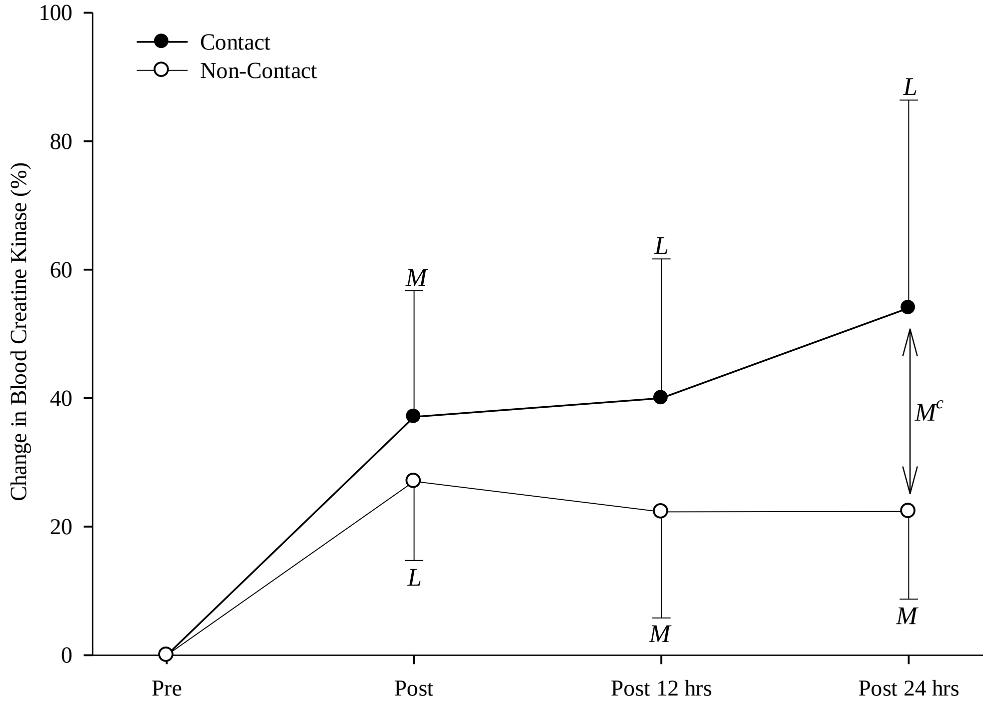

Figure 5.3. Changes in blood creatine kinase following the contact and non-contact small-sided games. Data are reported as means ± 95% confidence interval; *M* Denotes moderate effect size difference from baseline; *L* denotes large effect size difference from baseline; M^c denotes moderate effect size between conditions.

There was a significant main effect of time on countermovement jump power ($F_{1,38}$ = 18.26, p = 0.001, η_p^2 = 0.066). There were reductions in CMJ peak power following both games (Figure 5.4A) compared with baseline values (contact = 4939.4 ± 216.4 W; non-contact = 4977.39 ± 221.6 W). There was a moderate reduction in CMJ power immediately after the contact game (ES = -0.88 ± 0.82) and a large reduction following the non-contact game (ES = -1.42 ± 0.93). Reductions in CMJ power peaked 12 hours after both games (Contact ES = -1.40 ± 1.0; Non-contact ES = -2.25 ± 1.1). At 24 hours post game, there was a small reduction in CMJ power following the contact game (ES = -0.35 ± 0.63) and a moderate reduction following the non-contact game (ES = -1.13 ± 0.91). The decrease in CMJ power 24 hours after the games was moderately greater following the non-contact game compared with the contact game (ES = 0.65 ± 0.74). Furthermore, at each time point, there were practically meaningful differences between changes in CMJ power following the two games (immediately post likelihood = likely, 75%; 12 hours post likelihood = likely, 92%; 24 hours post likelihood = likely, 86%). Compared to baseline (contact = 1840.0 ± 79.3 N; non-contact = 1854.3 ± 85.1 N), there was no change in CMJ peak force following the contact game, but moderate reductions immediately (ES = -0.75 ± 0.56) and 12 hours following (ES = -0.82 ± 0.47) the non-contact game (Figure 5.4B).

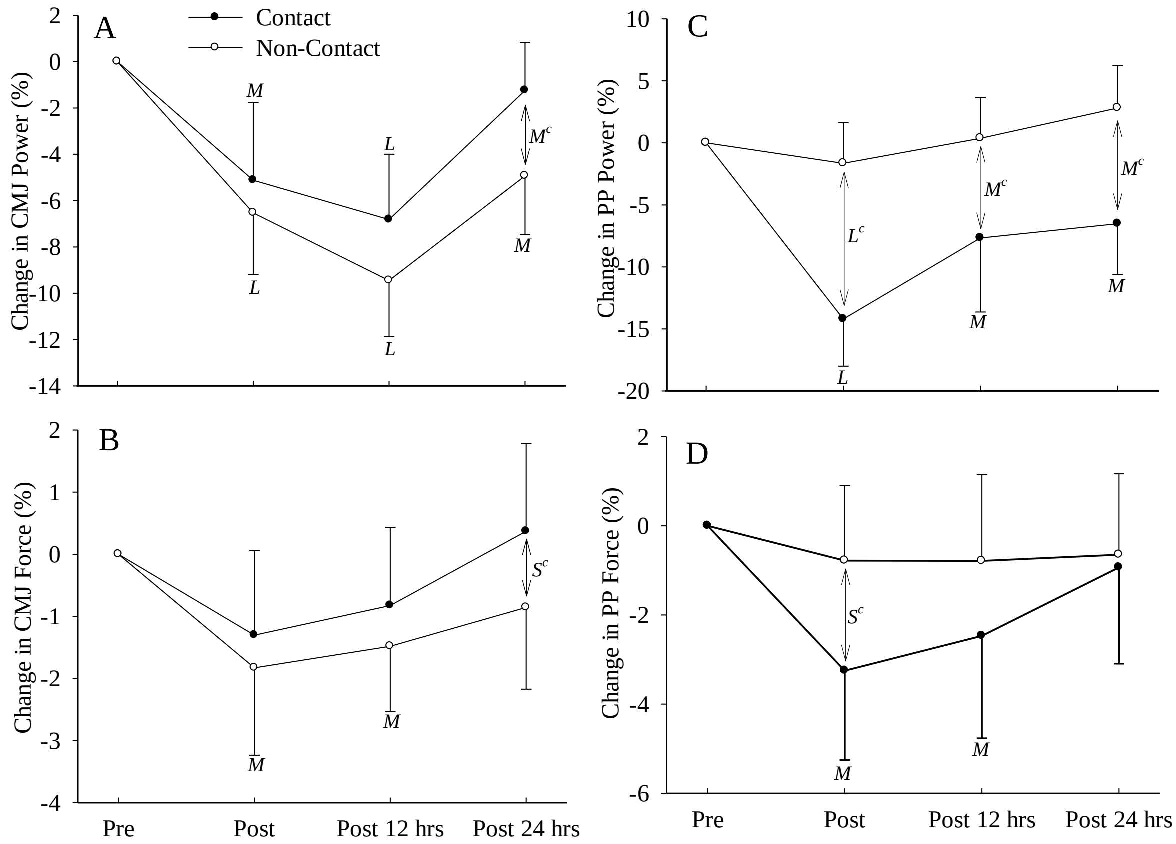

Figure 5.4. Changes in countermovement jump (CMJ) power (A), force (B) and plyometric push-up (PP) power (C) and force (D) following the contact and non-contact small sided games. Data are reported as means ± 95% confidence interval; a = moderate effect size difference from baseline; b = large effect size difference from baseline; ES = effect size.

There was a main effect of game ($F_{1,51}$ = 11.66, p = 0.003, η_p^2 =0.372), time ($F_{2,51}$ = 7.88, p = 0.001, η_p^2 = 0.284), and a group by time interaction ($F_{1,51}$ = 6.37, p = 0.002, η_p^2 =0.242) on PP peak power. There was no change in upper body peak power and force following the non-contact game (Figure 5.4C & D) compared with baseline (1820.1 ± 151.1 W; 791.6 ± 31.6 N). However, compared with baseline values (1898.7 ± 127.3 W; 801.0 ± 36.9 N) there was large reductions in PP peak power immediately following the contact game (ES = -1.86 ± 1.0), and moderate reductions at 12 (ES = -0.74 ± 0.87) and 24 hours (ES = -0.74 ± 0.94) post game. There was a large between group difference in PP peak power immediately post (likelihood = almost certain, 100%; ES = -1.31 ± 1.0) and moderate differences at 12 hours (likelihood =

very likely, 98%; ES = -0.68 ± 1.0) and 24 hours (likelihood = likely, 94%; ES = -0.87 ± 1.0) following the games. There were moderate reductions in PP peak force immediately following (ES = -1.08 ± 0.73) and 12 hours (ES = -0.77 ± 0.98) after the contact game. These reductions were practically meaningful compared with the non-contact game immediately (likelihood = very likely, 97%) and 12 hours (likelihood = likely, 89%) following the games.

There were small, but significantly greater reductions in perceived wellbeing following the contact game ($F_{1,22}$ = 10.88, p = 0.03, η_p^2 = 0.338; Contact ES = -0.48 ± 1.0; Non-contact ES = -0.28 ± 0.97). In addition, there were small reductions in muscle soreness following the contact game (ES = -0.29 ± 0.82), and only trivial reductions following the non-contact game (ES = -0.14 ± 0.23). Furthermore, the change in muscle soreness following the contact game was moderately greater than the change following the non-contact game (ES = 0.71 ± 0.31). There was a small, significant difference in the rating of perceived effort for each game, with a mean RPE of 6.9 ± 0.4 for the contact game and 6.3 ± 0.6 for the non-contact game (p = 0.05; likelihood = unlikely, 8%; ES = 0.41 ± 0.85).

5.2.5 Discussion

The aim of this study was to identify the influence of physical contact on the fatigue response to SSG. It is clear that the addition of physical contact to a SSG results in marked and longer lasting increases in CK compared to no physical contact. In addition, physical contact is responsible for increases in upper body neuromuscular fatigue. There were however, greater reductions in lower body muscle function following the non-contact game due to greater running loads. The results of this study demonstrate the great physical cost associated with contact efforts. Physical contact reduces upper body muscle function and this reduction may be related to muscle damage induced by training and competition. In addition, increasing the running demands of a SSG, results in greater lower body muscle fatigue.

The greater increases in blood CK observed following the contact game can be attributed to the physical contact. This substantiates the findings of others who have reported significant correlations between the number of contacts performed during competition and increases in

CK [27, 36]. Although blunt force trauma associated with collisions is thought to be the cause of this increases in blood CK, this cannot be ascertained. During this study, blunt force trauma would have been induced by the shoulder pummelling; however, eccentric muscle actions associated with the wrestling cannot be eliminated as a source of muscle damage. Indeed, the large increase in CK following the non-contact game suggests that eccentric contractions associated with high-speed movements still play a role in the muscle damage response. Compared with the non-contact SSG, the increases in blood CK were only moderately greater 24 hours following the contact SSG. This finding is not surprising given the relatively small volume of contacts performed (16 bouts) and the nature of these contacts. Contacts similar to competition in terms of number and intensity would likely result in more blunt force trauma, and therefore an accentuated increase in blood CK compared with that seen following the contact SSG. Nonetheless, it is clear that physical contact causes substantial increases in blood CK, indicative of skeletal muscle damage. Furthermore, given that elevations in CK could contribute to reductions in low-speed activity and RHIE frequency during competition [150], it would appear important to ensure CK concentrations are within “normal” ranges prior to competition. With this in mind, contact sessions should be performed well in advance of scheduled games. In addition, players who have performed large numbers of contacts during a game may require prolonged recovery.

There were reductions in PP power and force following the contact game, but no change following the non-contact game. This is consistent with previous research that reported increases in upper body neuromuscular fatigue during an intensified period of rugby league competition [30]. Collectively, these data indicate that upper body fatigue is present following training and competition. Moreover, it is clear that physical collisions are responsible for these increases in upper body fatigue, which may be expected given the large involvement of the upper body during physical collisions [27]. These increases in upper body fatigue following physical contact would suggest that monitoring upper body muscle function may be useful in contact sport athletes.

There were reductions in lower body power following both games, but greater changes following the non-contact game. The reason for this disparity could be related to the greater running loads performed (both low- and high-speed activity) during the non-contact games. Indeed, increases in high-speed movements appear to exacerbate reductions in lower body muscle function following a rugby league game [31]. Therefore, increases in running loads are likely to lead to greater reductions in CMJ performance. Collisions are also thought to contribute to lower body neuromuscular fatigue [27, 33]. However, in the current study, the use of the legs in the contact was limited, and therefore unlikely to have made a significant contribution to the changes in lower body function. Despite this, these data indicate that increasing the running loads of a SSG results in greater reductions in lower body muscle function and in particular power. As such, training should be carefully planned to ensure muscle function is not compromised prior to competition.

There were greater reductions in perceptual wellbeing following the contact game coupled with moderately greater reductions in perceived muscle soreness following the contact game. This may be due to greater increases in blood CK following the contact game compared with the non-contact game which suggests greater levels of muscle damage and potentially muscle soreness. Performing exercise in the presence of such muscle soreness can cause reductions in work capacity and increases in perceived effort [204]. Therefore, coaching staff may need to be mindful of increases in muscle soreness when prescribing training. In addition, despite greater running loads in the non-contact game, the contact game was associated with greater perceived effort, although this difference was small. This is in accordance with previous research that found greater perceived effort following repeated sprints and tackles compared to repeated-sprints alone [9]. Collectively these data highlight the psychological load associated with performing physical contacts.

5.2.6 Conclusions

The addition of physical contact to non-contact small-sided games results in upper body neuromuscular fatigue and marked and longer lasting increases in CK as well as increases in perceived effort compared to no physical contact. Collectively, these results clearly demonstrate the large physiological and psychological load associated with performing physical collisions. It should be noted however, that during the contact game, players only performed 16 contact and wrestle bouts. While the frequency of collisions were representative of that performed in match-play, these bouts did not match the absolute volume or the violent blunt force trauma of collisions associated with competition. As such, reductions in muscle function and increases in CK are likely to be more pronounced following competition, and contact training sessions. In addition, it should be noted that large inter-player variability exists in CK responses, and CK measurements should not be considered a direct test of muscle function. The large increases in CK observed following exercise may have been accentuated by plasma volume shifts although this is unlikely to explain the total changes in blood CK observed following the two games. A final limitation of the present study is that fatigue was only assessed up to 24 hours following the games, and it is unclear whether a peak in CK occurred following the contact game. As such, future research should aim to assess the complete time course of fatigue following commonly used small-sided games.

5.2.7 Practical Applications

- Small-sided games induce muscle damage and fatigue.
- Increases in running loads during small-sided games results in reductions in lower body neuromuscular function, while physical contact results in reductions in upper body neuromuscular function.
- Physical contact sessions should be performed well in advance of scheduled games.
- Strength sessions aimed at improving upper body power should be performed prior to, or more than 24 hours after contact sessions.
- Performing tackles is mentally demanding and players need to be exposed to the tackle demands of competition within training.

5.2.8 Acknowledgments

The authors would like to thank the coaching staff and players of the Melbourne Storm rugby league club for participating in and supporting this study.

5.3 Study 7: Influence of physical qualities on post-match fatigue in rugby league players

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of physical qualities on post-match fatigue in rugby league players. *J Sci Med Sport*, 2015, 18: 209-213.

5.3.1 Abstract

This study examined the influence of physical qualities on markers of fatigue and muscle damage following rugby league match-play. A between subjects experimental design was used. Twenty-one male youth rugby league players (age 19.2 ± 0.7 years; height 180.7 ± 5.6 cm; body mass 89.9 ± 10.0 kg) participated in the study. Yo-Yo intermittent recovery test (level 1), 3 repetition maximum back squat and bench press were assessed prior to 2 competitive fixtures. Neuromuscular fatigue (countermovement jump [CMJ] and plyometric push-up [PP]), and blood creatine kinase (CK) were assessed before and after match-play. During match-play, movements were recorded using microtechnology. Players were divided into high- and low-groups based on physical qualities. High Yo-Yo and squat performance resulted in greater loads during match-play ($p<0.05$). There were larger reductions in CMJ power in the low Yo-Yo group at both 24 (ES = -1.83), and 48 h post-match (ES = -1.33). Despite greater internal and external match loads, changes in CMJ power were similar between squat groups. There were larger increases in blood CK in the low Yo-Yo group at 24 (73% vs. 176%; ES = 1.50) and 48 h post-match (28% vs. 80%; ES = 1.22). Despite greater contact loads, the high squat group exhibited smaller changes in blood CK post-match (ES = 0.25 to 0.39). Post-match fatigue is lower in players with well-developed high-intensity running ability, and lower body strength, despite these players having greater internal and external match loads.

5.3.2 Introduction

Rugby league is an intermittent team sport where players repeatedly perform bouts of high-speed running and physical collisions interspersed with periods of low-speed activity [2]. These demands result in increased markers of muscle damage, neuromuscular and perceptual fatigue [27, 34]. While generally transient in nature, this fatigue typically persists for 24-48 h after competition, although muscle damage may last for several days [34]. High levels of residual fatigue and markers of muscle damage have the potential to compromise performance through reductions in low- and high-speed movements, as well as tackling proficiency [30, 150].

Understanding and managing the fatigue response to match-play may allow optimal preparation for subsequent performance. Whilst various interventions are often employed to facilitate recovery following match-play, their efficacy is often questioned [42, 43]. Currently, it is unclear whether any intrinsic qualities influence the fatigue response observed following competition. Findings from Australian rules football found that across a season, players with higher 6 min run performance showed smaller disturbances in blood creatine kinase (CK) prior to competition [40]. In addition, well-developed physical qualities reduce transient fatigue following physical exertion. In particular, greater aerobic fitness results in smaller decrements in repeated-sprint performance [45, 46]. Fitter athletes may experience smaller metabolic disturbances following high-intensity activity, resulting in less acute fatigue [44]. These data suggest that aerobic fitness could reduce residual fatigue and muscle damage following competition.

In addition to aerobic fitness, muscular strength has the potential to influence the fatigue response. Although collisions play a major role in the muscle damage and fatigue response [27, 47], high-speed movements also induce symptoms of fatigue [27, 30, 47]. Therefore, players who possess greater muscular strength and eccentric strength in particular, may be more suited to dealing with the forces associated with these movements. Indeed, greater strength appears to augment the stretch-shortening cycle, potentially placing less stress on the contractile components of the muscle [48, 49]. Byrne et al., [50] suggested that enhancing the stretch-shortening cycle capabilities of the muscle may moderate the effects of muscle damage. Therefore, greater muscular strength may limit neuromuscular fatigue and muscle damage following match-play.

The purpose of this study is to assess whether physical qualities influence post-match markers of fatigue in rugby league players. Such information would allow coaches to better manage post-game recovery practices and reduce disruption to training. It is hypothesised that greater high-speed running ability and muscular strength will be associated with reductions in post-game neuromuscular fatigue and markers of muscle damage.

5.3.3 Methods

5.3.3.1 Subjects

High-intensity intermittent running ability, and upper and lower body muscular strength were assessed in 21 male sub-elite youth rugby league players (age 19.2 ± 0.7 years; height 180.7 ± 5.6 cm; body mass 89.9 ± 10.0 kg). The players were from the same under 20's side of a Queensland Cup team. The Queensland Cup is a feeder competition to the Australian National Rugby League. Neuromuscular fatigue and blood CK were assessed before and after two competitive fixtures separated by 7 days. Prior to the study, players attended an information session outlining experimental procedures. Over the course of the testing period, players were asked to maintain their normal diet. Following each match, players engaged in no physical activity until reporting to training at 48 h post-match. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), informed consent and approval from the Australian Catholic University's ethical review board for human research was obtained.

5.3.3.2 Protocol

Within fourteen days prior to the first match of the study, players performed the Yo-Yo intermittent recovery test (IRT) level 1, as well as a 3 repetition maximum (RM) bench press and back squat at the start of two training sessions. Testing sessions were separated by two days. Players were free from injury at the time of testing, and avoided exercise for 48 h prior to each test. On the first night, players performed the Yo-Yo IRT level 1 to assess high-intensity intermittent running ability as described previously [183]. The test was performed on a floodlit grass pitch; players wore studded boots and training kit to complete the test. The typical error of measurement (TE) for this test is 4.9% [183].

Two days later, upper and lower body muscular strength was assessed using a 3 repetition maximum (RM) bench press and back squat respectively, using free-weight Olympic bars. Players were given two warm-up sets of increasing loads before attempting to lift their previous 3RM. If successful, after a 3-5 min rest, players increased the load by a minimum of 5 kg until they reached their new 3RM. The tests were conducted using the same procedures outlined by Baker and Nance [122]. The TE for the bench press and back squat was 2.5% and 3.5% respectively.

5.3.3.3 Markers of Fatigue

Neuromuscular fatigue was assessed immediately before, immediately after, 24 h, and 48 h following both games. Lower and upper body peak power was assessed using a countermovement jump (CMJ) and a plyometric push-up (PP) [30]. For the PP, players started in a push-up position with their hands on the force platform in a self-selected position, and arms extended. On the experimenter's signal, players were required to lower their body by flexing the elbows to a self-selected depth before extending the elbows as fast as possible so that their hands left the platform. Both exercises were performed on a force platform (Kistler 9290AD Force Platform, Kistler, USA) interfaced with a laptop (Acer Aspire 2930, Acer, UK) running manufacturer designed software (QuattroJump, Kistler, USA). Previous research has reported TE for CMJ peak power as 2.9% [151]. The TE for PP peak power was 3.5%.

Blood CK was assessed as an indirect marker of muscle damage at the same time points as neuromuscular fatigue. After pre-warming of the hand, a 30 μl sample of blood was taken from a fingertip and analysed using a colorimetric assay procedure (Reflotron, Boehringer

Mannheim, Germany). Before each testing session, the instrument was calibrated in accordance with manufacturer recommendations [27, 30]. The TE for CK was 3.3%.

5.3.3.4 Match Activities

Game movements were assessed by GPS microtechnology devices. The GPS units sampled at 10 Hz (Team S4, Firmware 6.88, Catapult Sports, VIC, Australia) and included 100 Hz tri-axial accelerometers, gyroscopes, and magnetometers to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and subsequently analysed (Sprint, Version 5, Catapult Sports, VIC, Australia). Data were categorised into low (0-5 $m{\cdot}s^{-1}$), high (≥5.1 $m{\cdot}s^{-1}$), and very high-speed (≥7.1 $m{\cdot}s^{-1}$) movement bands. Repeated high-intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration (≥2.78 $m{\cdot}s^{-2}$), high-speed, or contact efforts with less than 21 s between each effort [2]. These units have been shown to offer a valid and reliable method of quantifying movements and collisions that are commonplace in rugby league [160, 164]. To assess internal load, within 30 min following each game, rating of perceived exertion (RPE [CR-10]) was recorded and multiplied by minutes played [205].

5.3.3.5 Statistical Analyses

To control for playing position, players were divided into forwards and backs. A median split, based on fitness test results, was used to further divide the players into high- and low-fitness groups. This ensured there was an even spread of positions between groups. The differences in fatigue, muscle damage and match demands between the high- and low-groups and changes over time were determined using traditional significance testing, and magnitude based inferences. In order to determine changes in neuromuscular function and blood CK and differences between groups, a two-way (group x time) repeated measures ANOVA was used to determine the statistical significance of any differences. To compare differences in match demands between high- and low-fitness groups, independent-samples t-tests were used.

Based on the real-world relevance of the results, magnitude based inferences were used to assess the meaningfulness of any differences. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x the between subject standard deviation. Based on 90% confidence intervals , the thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; >99% almost certain.[174] The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic ± 95% confidence intervals [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± standard deviation (SD); the significance level was set at $p<0.05$.

5.3.4 Results

Players were divided into high- and low-groups based on Yo-Yo IRT (high: Yo-Yo IRT = 1516 ± 182 m, body mass = 86.9 ± 9.3 kg; low: Yo-Yo IRT = 1196 ± 70 m, body mass = 90.4 ± 10.3 kg); 3RM back squat (high: squat = 145 ± 17 kg, body mass = 87.9 ± 10.1 kg; low: squat = 119 ± 9 kg, body mass = 90.3 ± 9.3 kg); and 3RM bench press (high: bench press = 113 ± 12 kg, body mass = 89.6 ± 19.0; low: bench press = 91.5 ± 3 kg, body mass = 85.6 ± 17.2 kg).

There was no significant difference in playing time between high- and low-groups based on any physical quality. Players with high Yo-Yo IRT covered significantly greater distances at high- ($p = 0.028$; ES = 0.88 ± 0.21) and very high-speeds ($p = 0.023$; ES = 0.91 ± 0.27). Players with high back squat performance had greater total ($p = 0.040$; ES = 0.73 ± 0.15), and high-speed distances ($p = 0.011$; ES = 0.99 ± 0.22), internal load ($p = 0.018$; ES = 1.00 ± 0.17), collisions ($p = 0.032$; ES = 0.99 ± 0.11) and RHIE bouts ($p = 0.020$; ES = 0.89 ± 0.13) (Table 5.3).

Table 5.4. Differences in match demands between players based on Yo-Yo, back squat, and bench press performance. †

	Yo-Yo			Back Squat			Bench Press		
	High	Low	ES	High	Low	ES	High	Low	ES
Absolute Demands									
Playing Time (min)	54 ± 22	49 ± 20	0.27	57 ± 20	44 ± 19	0.65	56 ± 18	47 ± 22	0.46
Distance (m)	5391 ± 1350	4898 ± 1658	0.33	5587 ± 1033*	4531 ± 1754	0.73	5325 ± 1254	4958 ± 1740	0.24
LSA (m)	4927 ± 1212	4564 ± 1601	0.26	5158 ±1038	4231 ± 1660	0.67	4935 ± 1217	4556 ± 1596	0.27
HSR (m)	332 ± 126*	230 ± 104	0.88	323 ± 102*	216 ± 116	0.99	282 ± 126	275 ± 129	0.06
VHSR (m)	53 ± 48*	20 ± 17	0.91	46 ± 40	24 ± 36	0.57	37 ± 31	35 ± 45	0.07
Contact Efforts (no.)	23 ± 9	26 ± 12	0.26	29 ± 10*	20 ± 9	0.99	27 ± 11	22 ± 9	0.49
RHIE Bouts (no.)	3 ± 2	3 ± 3	0.03	4 ± 3*	2 ± 1	0.89	3 ± 3	3 ± 2	0.05
Internal Load (AU)	314 ± 168	273 ± 152	0.26	373 ± 148*	244 ± 107	1.00	329 ± 169	292 ± 110	0.26
Relative Demands									
Distance ($m \cdot min^{-1}$)	93 ± 9	93 ± 11	0.06	91 ± 7	95 ± 13	0.33	91 ± 7	94 ± 12	0.32
LSA ($m \cdot min^{-1}$)	85 ± 8	86 ± 10	0.08	84 ± 5	88 ± 11	0.48	84 ± 6	87 ± 11	0.30
HSR ($m \cdot min^{-1}$)	6 ± 2*	4 ± 1	0.87	5 ± 2	5 ± 2	0.41	5 ± 1	5 ± 2	0.42
VHSR ($m \cdot min^{-1}$)	0.9 ± 1.0	0.5 ± 0.6	0.56	0.8 ± 0.9	0.6 ± 0.8	0.26	0.7 ± 0.6	0.7 ± 1.0	0.04
Contacts (no./min)	0.4 ± 0.2	0.5 ± 0.2	0.45	0.5 ± 0.2	0.4 ± 0.2	0.35	0.5 ± 0.2	0.4 ± 0.2	0.12
RHIE Bout Frequency	1 every 33 min	1 every 31 min	0.09	1 every 31 min	1 every 34 min	0.13	1 every 36 min	1 every 28 min	0.36

† Data are presented as means ± SD. Yo-Yo = Yo-Yo intermittent recovery test (level 1); Back Squat = 3 repetition maximum back squat; Bench Press = 3 repetition maximum bench press. LSA = low-speed activity (<5 $m \cdot s^{-1}$); HSR = high-speed running (≥5.1 $m \cdot s^{-1}$); VHSR = very-high speed running (≥7.1 $m \cdot s^{-1}$); RHIE Bout = repeated high-intensity effort bout (3 or more maximal acceleration, high speed or contact efforts with ≤21 seconds between each effort); Internal Load = rating of perceived exertion x minutes played. * Denotes significantly greater than the low group ($p<0.05$). ES = effect size difference; effect sizes of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively.

The games induced significant and large reductions in CMJ power, peaking immediately post-match (-6.5 ± 7.0%; $p = 0.002$; ES = -1.31 ± 0.43; likelihood = likely, 92%) before gradually returning towards baseline at 24 h post-match (-3.1 ± 8.2%; $p = 0.514$; ES = -0.53 ± 0.67; likelihood = possibly, 69%), and 48 h post-match (-1.5 ± 5.9%; $p = 1.00$; ES = -0.36 ± 0.55; likelihood = possibly, 70%). When players were divided into high- and low-groups based on Yo-Yo performance, there was a significant main effect of time ($p = 0.018$) and group ($p = 0.032$), as well as a group by time interaction ($p = 0.017$) for lower body neuromuscular fatigue (Figure 5.5A). There were large reductions in CMJ power in both groups immediately post-match (high-group ES = -1.80; low-group ES = -1.64). By 24 h post-match CMJ power in the high Yo-Yo group had returned to baseline values; in the low-group, there were still large reductions at 24 h (ES = -2.94 ± 0.95) and 48 h (ES = -1.51 ± 0.74) post-match. Furthermore, there were large differences between groups at these time points (24 h ES = -1.83 ± 0.52, likelihood = likely, 76%; 48 h ES = -1.33 ± 0.48, likelihood = possibly, 52%). There was no difference between groups for changes in CMJ power at any time point when players were split into high- and low-groups based on 3RM squat (Figure 5.5B; $p = 0.948$), and 3RM bench press (Figure 5.5C; $p = 0.357$).

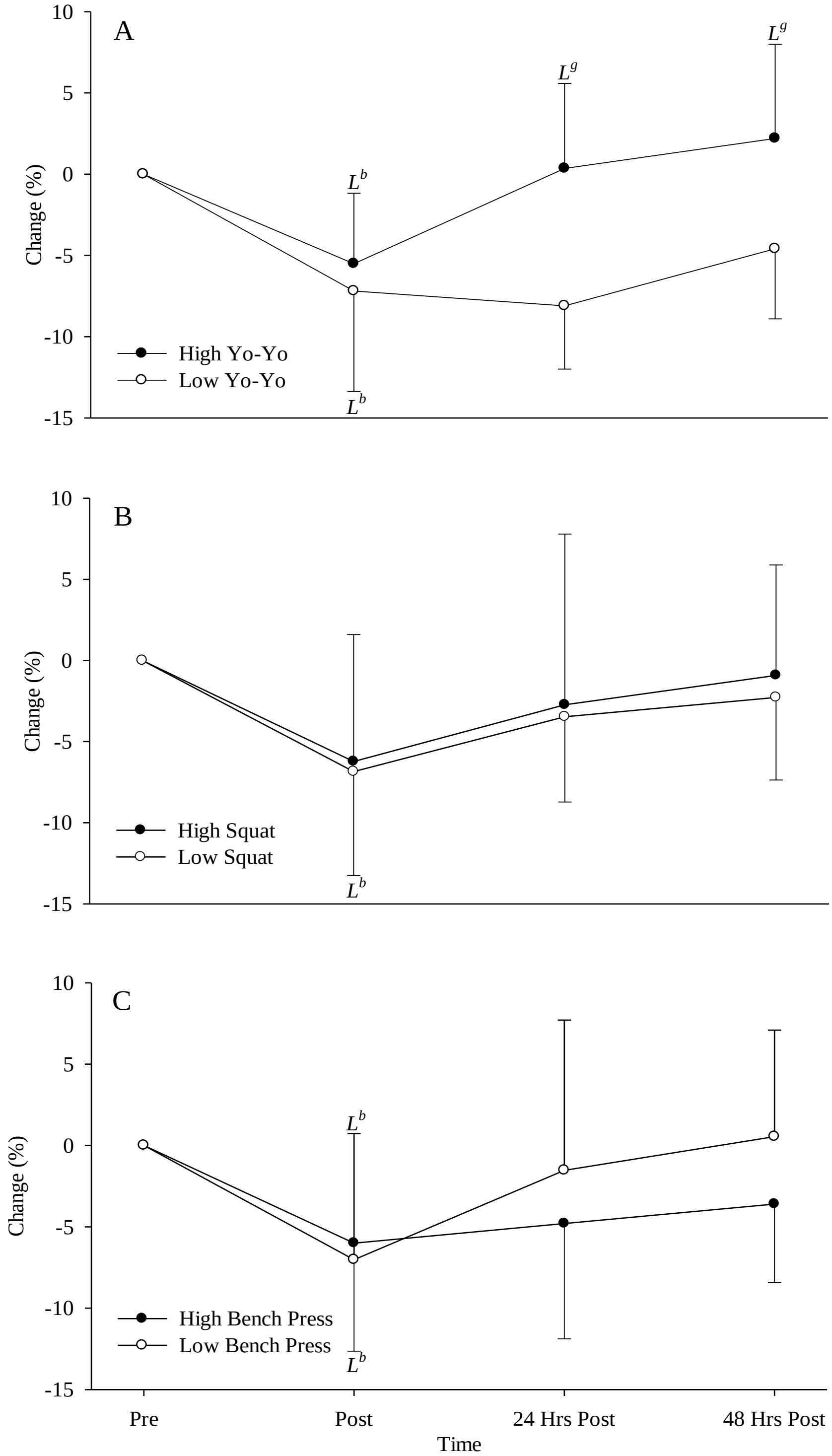

Figure 5.5. Changes in countermovement jump peak power following match-play with players split into high- and low-fitness groups based on Yo-Yo (A), back squat (B), and bench press (C) performance. Data are presented as means ± SD. L^b Denotes a large effect size difference ≥1.20) compared with baseline. L^g Denotes a large effect size difference between groups.

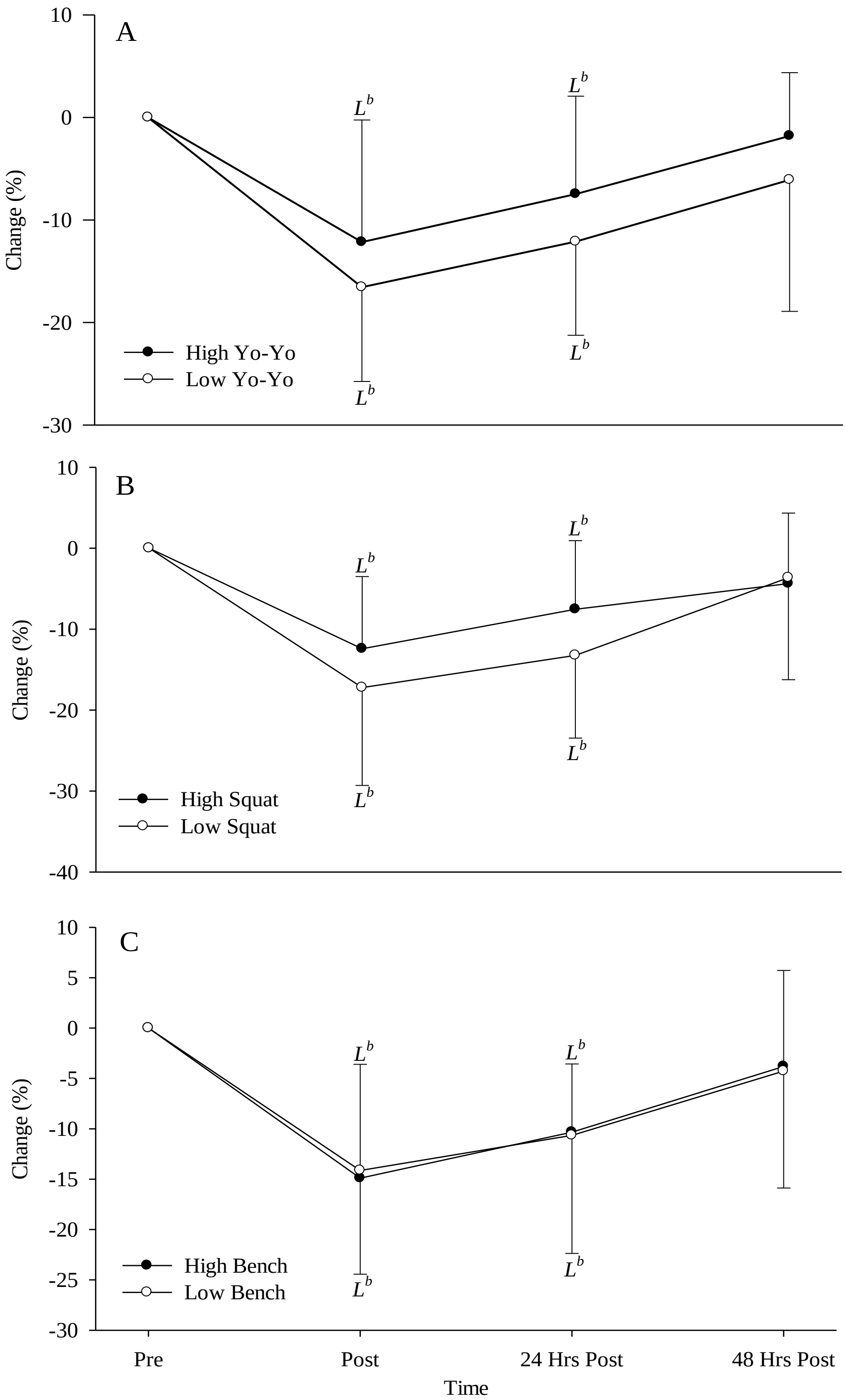

Figure 5.6. Changes in plyometric push-up peak power following match-play with players split into high- and low-fitness groups based on Yo-Yo (A), back squat (B), and bench press (C) performance. Data are presented as means ± SD. L^b Denotes a large effect size difference (≥1.20) compared with baseline.

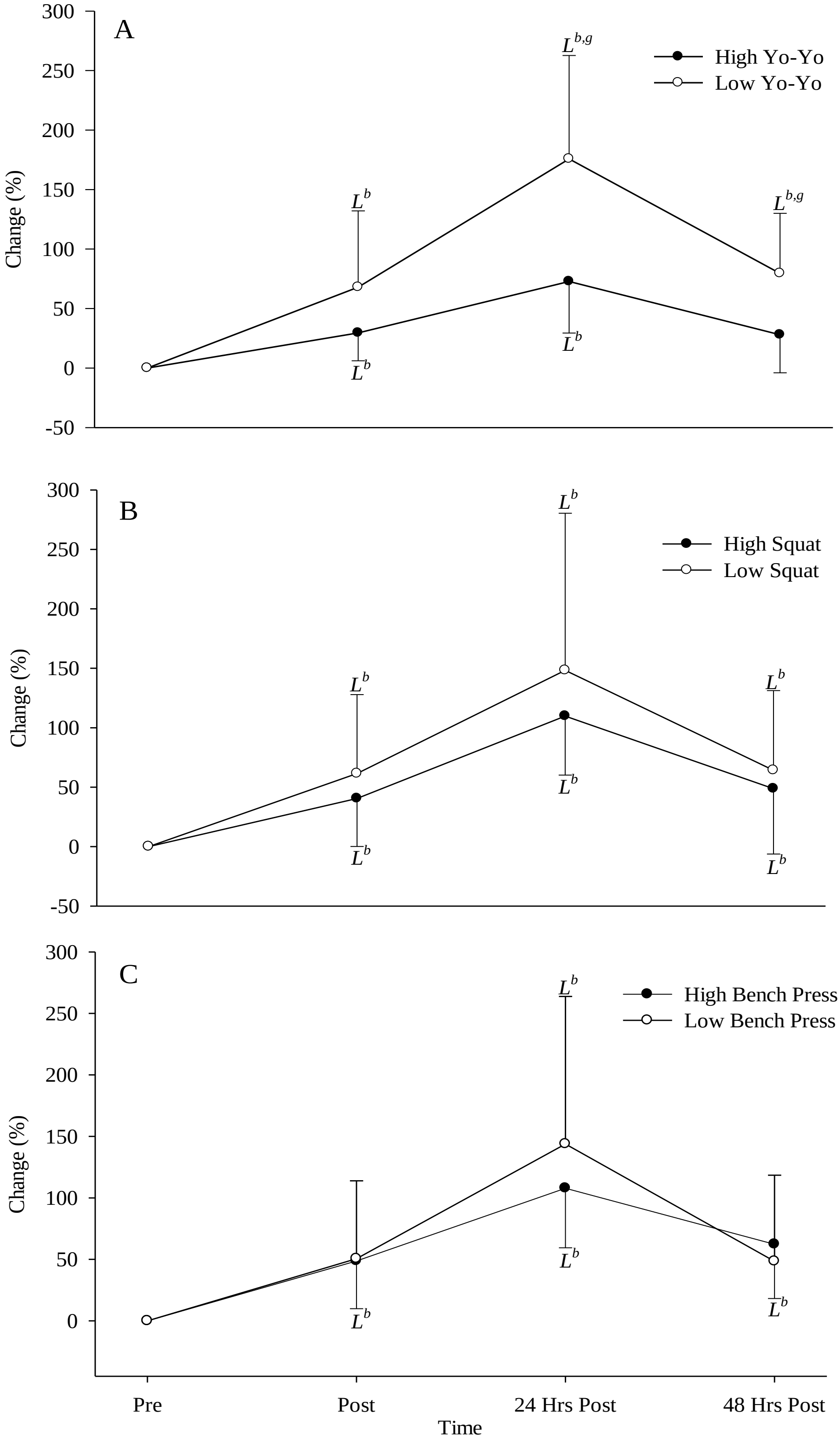

Figure 5.7. Changes in blood creatine kinase following match-play with players split into high- and low-fitness groups based on Yo-Yo (A), back squat (B), and bench press (C) performance. Data are presented as means ± SD. L^b Denotes a large effect size difference (≥1.20) compared with baseline. L^g Denotes a large effect size difference between groups.

The games induced significant and large reductions in PP power, peaking immediately post-match (-14.6 ± 10.4; p = 0.001; ES = -1.97 ± 0.61; likelihood = almost certain, 100%), before gradually recovering at 24 h (-10.2 ± 9.5; p = 0.001; ES = -1.54 ± 0.53; likelihood = very likely, 96%) and 48 h post-match (-4.1 ± 10.2%; p = 0.412; ES = -0.56 ± 0.36; likelihood = likely, 90%). When players were split into high- and low-groups based on Yo-Yo performance (Figure 5.6A), there were greater reductions in PP power in the low Yo-Yo group, however, these differences were non-significant (p = 0.691) and small in magnitude (ES = -0.41 to -0.50). There was a similar non-significant trend when players were divided into groups based on 3RM squat (Figure 5.6B; p = 0.359), with the low-group showing moderately greater reductions in PP power 24 h post-match (ES = -0.83 ± 0.65). There was no difference in PP power between high and low bench press groups (Figure 5.6C; p = 0.908).

Overall, there were significant and large increases in blood CK at each time point, peaking 24 h post-match (126 ± 92%; p = 0.001; ES = 1.93 ± 0.98; likelihood = almost certain, 100%). Although CK showed some recovery, it was still 55 ± 58% elevated above baseline levels (p = 0.002; ES = 1.34 ± 0.75; likelihood = almost certain, 100%) 48 h post-match. Based on Yo-Yo performance, there was a significant main effect of group (p = 0.015) and a group by time interaction (p = 0.027) for blood CK (Figure 5.7A). Compared with the high-Yo-Yo group, there were larger increases in blood CK in the low-group at 24 h (73 ± 43% vs. 176 ± 99%; ES = 1.50 ± 0.78; likelihood = very likely, 99%) and 48 h post-match (28% vs. 80%; ES = 1.22 ± 0.61; likelihood = very likely, 98%). There were small differences between groups based on 3RM squat (Figure 5.7B; p = 0.632; ES = 0.25 to 0.39) and bench press (Figure 5.7C; p = 0.531; ES = 0.03 to 0.39).

5.3.5 Discussion

This is the first study to determine the influence of physical qualities on the fatigue responses following rugby league competition. We found that a sub-elite game of youth rugby league resulted in significant neuromuscular fatigue to both the upper and lower body, and increased markers of muscle damage. Reductions in CMJ power peaked immediately post game, recovering by 48 h post-match; reductions in PP power peaked immediately post-game, and was still reduced 48 h post-match; CK peaked at 24 h, and despite decreasing, was still elevated at 48 h post-match. Despite players with high Yo-Yo IRT performance covering greater high-speed distances, these players showed a faster recovery in CMJ power, and smaller increases in blood CK following match-play. Additionally, high squat performance was associated with greater running, collision, repeated-effort, and internal loads, yet these players displayed similar reductions in CMJ power, and smaller changes in upper body power, and blood CK. This study highlights that in order to minimise the fatigue response following match-play, coaches should aim to maximise high-intensity running ability and lower body strength.

Whilst there were reductions in CMJ power post-match, these reductions were lower in players with high Yo-Yo IRT performance, despite these players experiencing greater match running loads. Although there were similar reductions in CMJ power based on lower and upper body strength, the collision, running, repeated-effort, and internal loads were greater in the high squat group compared with the low squat group. A potential explanation for this could be that players with well-developed high-intensity running ability and lower body strength possess greater eccentric strength, and the ability to utilise the stretch-shortening cycle [48, 49]. Therefore the high-intensity movements that players are required to perform in competition result in less neuromuscular fatigue. In addition, enhanced aerobic qualities appear to reduce the metabolic disturbances following intense intermittent exercise [45, 46]. In accordance with previous findings [24, 28], players with well-developed high-intensity running ability and lower body strength perform greater total and high-speed distances and RHIE bouts during competition. With this in mind, high-intensity running ability and lower body strength appear important for physical performance and limiting post-match reductions in CMJ power.

Based on physical qualities, there was little difference in the reductions in PP peak power between high- and low-groups. Despite this, the reductions in peak power were slightly greater in both low Yo-Yo IRT and back squat groups. Indeed, there was a moderately greater reduction in peak power at 24 h post-match in the low squat group. Given that contact efforts account for the majority of upper body fatigue [47], and that the high squat group performed significantly more contact efforts, this result is even more noteworthy. A potential explanation could be that these players may be more likely to utilise their lower body for strong leg drive in order to 'win' the contact rather than wrestling the player onto their back using their upper body musculature. Although speculative, this could have preserved upper body power in players with high lower body strength. Collectively, these data suggest that despite greater absolute match loads, well developed high-intensity running ability and lower body strength help protect players against post-match upper body neuromuscular fatigue.

Consistent with previous research [27], there were large increases in CK peaking 24 h post-match independent of physical qualities. There were significantly greater increases in CK in the low Yo-Yo IRT group that were large in magnitude at 24 and 48 h post-match. Along with previous research that found well-developed aerobic fitness resulted in smaller disturbances in blood CK [40], this study suggests that high-intensity running ability also has comparable protective effects. Similar to the reductions in CMJ power, this may be explained by the muscles being better conditioned to tolerate the eccentric and stretch-shortening cycle muscle actions associated with the high-intensity movements of match-play, which traditionally increases CK [50]. Although the high squat group performed significantly more contact efforts, which are largely responsible for increases in CK [47], they recorded moderately smaller increases in CK. A reason for this could be that lower body strength results in greater leg drive in contact, resulting in more dominant tackles [96, 141], and minimising blunt force trauma that elevates CK [27]. Given the potential for elevated CK to compromise match performance [30, 150], it would appear vital to limit these increases. As such, developing lower body strength and high-intensity running ability is vital to guard against unmanageable increases in blood CK.

5.3.6 Conclusions

The results of this study demonstrate that sub-elite youth rugby league games induce significant amounts of neuromuscular fatigue and markers of muscle damage. Lower body neuromuscular fatigue recovered by 48 h post game, whereas upper body fatigue, and blood CK was still elevated. Post-match fatigue was reduced in players with well-developed high-intensity running ability, and lower body strength despite these players having greater internal and external absolute loads during competition. Therefore, strength and conditioning coaches should aim to maximise lower body strength and high-intensity running ability during the pre-season period to minimise the fatigue response to competition. Although this study gives an insight into the influence physical qualities may have on the post-match fatigue response, there are some limitations that should be acknowledged. The fatigue responses were only assessed following two competitive games. Using a greater number of games to increase the sample size should be an area of future research. Furthermore, we only investigated a limited number of physical qualities. Future studies should assess the influence of a broader range of qualities on post-match fatigue.

5.3.7 Practical Applications

- Lower body fatigue is recovered by 48 h post-match in sub-elite youth rugby league players, although this can be reduced to 24 h with well-developed high-intensity running ability.
- Upper body fatigue and markers of muscle damage are still present 48 h after match-play.
- Improving high-intensity running ability and lower body strength is likely to minimise post-match fatigue and muscle damage markers.

5.3.8 Acknowledgements

The authors would like to thank the players and staff of the Norths Devils Rugby League Club for participating in this study. No sources of funding were used in this study.

5.4 Study 8: Influence of playing standard and physical fitness on activity profiles and post-match fatigue during intensified rugby league competition

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5.4.1 Abstract

The purpose of this study was to determine whether the fatigue responses to the same intensified rugby league competition differed depending on playing standard and physical fitness. A between groups, repeated measures experimental design was used. Players from a high-standard (n = 15) and a low-standard (n = 16) junior rugby league team had lower-body neuromuscular fatigue, perceptual wellbeing, and blood creatine kinase (CK) assessed over an intensified competition. Global positioning system units measured match activity profiles and rating of perceived exertion assessed internal loads. Players were divided into high- and low-fitness groups across the two standards based on Yo-Yo intermittent recovery test performance. Playing intensity increased with playing standard and fitness levels (high-standard = 92 ± 6 $m \cdot min^{-1}$ *vs.* 88 ± 6 $m \cdot min^{-1}$; low-standard = 88 ± 2 $m \cdot min^{-1}$ *vs.* 83 ± 6 $m \cdot min^{-1}$). Despite greater internal and external loads, high-fitness players showed smaller reductions in lower-body power (high-standard ES = -0.74; low standard ES = -0.41). High-standard players had smaller increases in blood CK (77 ± 94% *vs.* 113 ± 81%; ES = -0.41), primarily due to very small increases in the high-fitness group (50 ± 45%). Increased fitness leads to greater internal and external workloads during intensified competition, smaller increases in blood CK, and less neuromuscular fatigue. Maximising player fitness should be a primary goal of coaches in order to increase match workloads and reduce post-match fatigue during intensified competition.

5.4.2 Introduction

Rugby league is a physically demanding sport that involves periods of high-intensity activity (e.g. high-speed running, sprinting, physical contact) interspersed with periods of low-intensity activity (e.g. standing, walking jogging) [2]. During competition, players typically cover relative distances of 90-100 $m.min^{-1}$ [2, 5, 8], which increases with playing standard [58]. In addition to these running demands, players frequently engage in physical contact (i.e. tackles, hit-ups, and wrestles) during attack and defence [5]. Gabbett et al., [10] reported that players performed 24-47 contact efforts during a game at an average frequency of 0.38-1.09 $contacts.min^{-1}$, although players can perform up to 1.9 ± 0.7 $contacts.min^{-1}$ depending on playing position, phase of play and field position [25].

Given the intense physical demands of rugby league, it is no surprise increased markers of muscle damage, as well as neuromuscular and perceptual fatigue are observed following match-play [27, 34, 139]. While this fatigue is generally transient in nature, typically persisting for 24-48 h after competition, muscle damage can last for five days [34]. As such, during tournaments or periods of congested fixtures when players may be required to play multiple games within a week, insufficient recovery may occur [30]. Indeed, during rugby league [30, 150], basketball [29], and soccer tournaments [37], fatigue accumulates, which compromises high-intensity match activities during the latter stages of the competition. Johnston et al., [150] showed relative distance covered at high-speeds was reduced by 50 and 60% in the final two games of an intensified rugby league tournament. Whilst studies from basketball and soccer suggest that recovery strategies, and in particular cold water immersion, may be useful to minimise fatigue-mediated reductions in performance during intensified competitions [29, 37, 206], physical qualities such as high-intensity running ability and lower body strength, also appear to play an important role in minimising post-match fatigue in rugby league players [139]. Although physical qualities may attenuate post-match fatigue following regular games [139], it is unclear whether they could help minimise fatigue that may occur during intensified rugby league competition [30, 150].

It is well documented that the intensity of match-play increases with competitive standard [58, 60, 61]. Indeed, Gabbett reported that during a junior rugby league tournament, first division players covered greater meters per minute at both low- and high-speeds, and engaged in a higher frequency of collisions and repeated high-intensity effort (RHIE) bouts than third division players [60]. As such, it would seem logical that increased playing intensity would lead to greater fatigue; however, this may be offset by enhanced physical qualities [139]. As playing standard increases in junior players, so too do physical qualities [73, 91], which appear central to minimising post-match fatigue [139]. With this in mind, the aims of this study were to investigate whether there was a difference between (1) fatigue responses based on playing level (2) fatigue responses based on physical fitness and (3) match activity profiles based on playing standard and physical fitness during the same intensified rugby league competition. It was hypothesised that players competing in the first division (high-standard) would have smaller increases in fatigue despite increased match intensity than players competing in the third division (low-standard) of the competition. In addition, we hypothesised that players from both high- and low-standard teams with well-developed physical qualities would experience less fatigue and greater workloads over the course of the competition.

5.4.3 Methods

5.4.3.1 Design

In order to test our hypotheses, a between groups, repeated measures experimental design was used. Players from two junior teams (one high- and one low-standard) were tracked for markers of fatigue (neuromuscular and perceptual wellbeing) and muscle damage (blood creatine kinase [CK]) during an intensified rugby league competition. In addition, global positioning system (GPS) microtechnology provided information on the activity profiles of players during matches. To assess the impact of physical fitness on match activities and post-match fatigue, players were also divided into high- and low-fitness groups based on their Yo-Yo intermittent recovery rest (IRT) level 1 performance.

5.4.3.2 Subjects

Thirty-one junior rugby league players (age 16.5 ± 0.5 years; body mass 79.6 ± 11.6 kg) competing for two separate schools in the 2014 Confraternity Shield tournament volunteered to participate in the study. One team was competing in the first division of the competition, and represented the high-standard team (*entire team*, n = 15; age 16.6 ± 0.5 years; body mass 78.5 ± 9.9 kg; *high-fitness group*, n = 8; age 16.6 ± 0.6 years; body mass 78.2 ± 8.8 kg; *low-fitness group,* n = 7; age 16.5 ± 0.6 years; body mass 78.9 ± 11.2 kg), the second team was competing in the third division, representing the low-standard team (*entire team,* n = 16; age 16.5 ± 0.6 years; body mass 79.6 ± 13.4 kg; *high-fitness group,* n = 8; age 16.3 ± 0.4 years; body mass 77.2 ± 10.8 kg; *low-fitness group,* n = 8; age 16.7 ± 0.6 years; body mass 84.8 ± 16.6 kg). The tournament took place in July, three months into the competitive season. All players were free from injury at the time of testing and were asked to maintain their normal diet throughout the competition; water was available *ad libitum* throughout. Before the study, players attended a familiarisation session and received an information sheet outlining experimental procedures, and the associated risks and benefits of participation. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), players received an information sheet outlining experimental procedures; written informed consent was obtained from each player and their legal guardian. The study was approved by the Australian Catholic University ethical review board for human research.

5.4.3.3 Protocol

Ten days prior to the tournament, the Yo-Yo IRT level 1 was used to assess high-intensity intermittent running ability [183]. The test was performed at 15:00 hrs on a grassed playing surface at the start of a training session; players wore studded boots and training kit to complete the test. The test requires players to complete a 20 m shuttle at progressively faster speeds whilst keeping in time with an audio signal. Between each shuttle, there is a 10 s period of active recovery involving a jog/walk around a cone placed 5 m from the start/finish line. When players failed to keep in time with the audio signals on 2 consecutive occasions they were deemed to have failed the test; the last level successfully completed, and the corresponding metres covered, were used as the final score for the test. The Players were asked to maintain their normal diet and refrain from physical activity during the 24 hours prior to the test. Some of the players were unfamiliar with the test so the first two levels of the test were incorporated into the warm-up to familiarise players with the test protocol. The typical error of measurement (TE) for this test is 4.9% [183]. A schematic overview of the protocol can be seen in Figure 5.8.

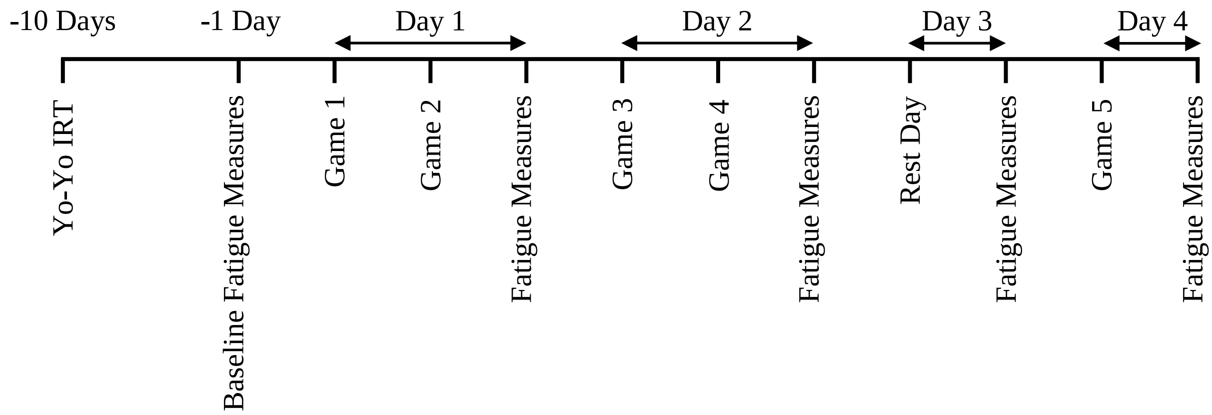

Figure 5.8. A schematic overview of the data collection protocol. Yo-Yo IRT = Yo-Yo intermittent recovery test (level 1); Fatigue Measures were conducted within 1 hour after the final game of each day and included a countermovement jump, blood creatine kinase, and perceptual wellbeing.

The first 4 games of the tournament were 40 min (2 x 20 min halves), with the final game being 50 min (2 x 25 min halves) in duration. Two games were played on both days 1 and 2, no games on day 3 and one game on day 4, totalling 5 games (210 min) over a 4 day period. Baseline measurements of neuromuscular fatigue, muscle damage, and perceived wellbeing were assessed approximately 12 hrs prior to game 1. Subsequent fatigue and muscle damage measures were taken within 1 hr of the final match of each day. On day 3, when no games were played, fatigue measures were assessed at the same time as they were on other days (~14:00-16:00 hrs). The average temperature, rainfall, and humidity over the competition period were 20.6 ± 2.2 °C, 0.00 ± 0.00 mm, and 51.0 ± 15.3%, respectively.

5.4.3.4 Markers of Fatigue

Lower-body neuromuscular fatigue was assessed using peak power from a single countermovement jump (CMJ) performed on a force platform (Kistler 9290AD Force Platform, Kistler, USA) interfaced with a laptop (Acer Aspire 2930, Acer, UK) running manufacturer designed software (QuattroJump, Kistler, USA) [30]. Players kept their hands on their hips throughout the jump; no instruction was given on the depth of the countermovement, but players were asked to jump as high as possible on the experimenter's signal in line with previous methodology [30]. The typical error of measurement (TE) from our laboratory for CMJ peak power is 3.5%. Peak power was used to assess neuromuscular fatigue as it offers good reliability and ensures consistency with previous rugby league literature [30, 33, 34, 47, 139].

Whole-blood CK activity was used as a marker of muscle damage. A 30 µl sample of blood was taken from a fingertip and immediately analysed using a colorimetric assay procedure (Reflotron, Boehringer Mannheim, Germany). Before each testing session, the instrument was calibrated in accordance with the manufacturer recommendations. The "normal" reference range for CK activity, as provided by the manufacturer using this method, is 24–195 $IU \cdot l^{-1}$ [27, 30, 189]. The TE for assessing CK was 3.3%.

Each day, perceived wellbeing was assessed by the experimenter asking players to rate feelings of fatigue, lower- and upper-body muscle soreness, sleep quality, mood and stress on 0-5 Likert scales, with the individual scores summated to give an overall wellbeing score using methods outlined previously [30]. The test re-test reliability for the perceptual wellbeing questionnaire was determined by having 12 rugby league players complete the questionnaire on two separate occasions, 7 days apart following 36 hours of no physical activity; the TE for perceptual wellbeing was 3.0%. Additionally, 30 min after each game, rating of perceived exertion (RPE) was recorded using a modified RPE scale (CR-10) to rate how hard players perceived each game. The RPE score was then multiplied by the number of min played to determine session RPE as a measure of internal load [172]. This method of assessing internal loads has shown to have appropriate levels of validity and reliability (TE = 4.0%) in rugby league players [184].

5.4.3.5 Match Activities

Activity profiles during competition were assessed by GPS analysis. Prior to the warm-up before each game, players were fitted with the GPS vest and unit; the unit was switched on, and inserted into a padded compartment at the rear of the vest, positioned between the shoulder blades. The GPS units sampled at 10 Hz (Team S4, Catapult Sports, VIC, Australia) and included a tri-axial accelerometer and gyroscope sampling at 100 Hz to provide information on collisions. Data were downloaded to a laptop (Acer Aspire 2930, Acer, UK) and analysed using software provided by the manufacturer (Sprint, Version 5.1.1, Catapult Sports, VIC, Australia). Non-playing minutes were omitted from the analysis. Data were categorised into low (0-3.5 $m \cdot s^{-1}$), moderate (3.6-5.0 $m \cdot s^{-1}$) and high speed ($\geq$5.1 $m \cdot s^{-1}$) movement bands [62]; the total number of collisions was recorded as described previously [2]. In addition, the average speed of each game ($m \cdot min^{-1}$) was calculated in relation to the final speed reached by players on the Yo-Yo IRT ($m \cdot min^{-1}$) in order to express the speed of the match in relation to the physical capacity of each player. Repeated high-intensity effort (RHIE) bouts were classified as 3 or more maximal acceleration ($\geq$2.78 $m \cdot s^{-2}$), high-speed, or impact efforts with less than 21 s between each effort [2]. These units are reliable for quantifying movements commonplace in rugby league [160, 164, 166].

5.4.3.6 Statistical Analyses

In order to determine the influence of physical fitness on match activities and post-match fatigue, players from both the high- and low-standard team were matched for position (forwards and backs) before being divided into low and high-fitness groups, using a median split, based on Yo-Yo IRT performance. This ensured that there was an even number of forwards and backs in both fitness groups so that the fatigue responses were not influenced by the different match activities performed by each positional group. This provided us with four experimental groups based on Yo-Yo IRT performance: high-standard/high-fitness, high-standard/low-fitness, low-standard/high-fitness, and low-standard/low-fitness.

Differences in fatigue, muscle damage and activity profiles between the high- and low-standard and high- and low-fitness playing groups and changes over time were determined using traditional null hypothesis testing, and magnitude based inferences. To compare differences in Yo-Yo IRT performance and match activity profiles between high- and low-standard playing groups and fitness levels, a two-way group (high- *vs.* low-standard) x fitness (high-standard/high-fitness *vs.* high-standard/low-fitness *vs.* low-standard/high-fitness *vs.* low-standard/low-fitness) ANOVA was used. A three-way group (high- *vs.* low-standard) x time (Baseline *vs.* Day 1 *vs.* 2 *vs.* 3 *vs.* 4) x fitness (high-standard/high-fitness *vs.* high-standard/low-fitness *vs.* low-standard/high-fitness *vs.* low-standard/low-fitness) repeated measures ANOVA (SPSS 22.0, SPSS Inc, Chicago, IL, USA) was used to determine changes in neuromuscular fatigue, blood CK, and activity profiles between playing standards and fitness levels. If significant main effects were found, Bonferroni *post hoc* analyses were performed to locate the differences. Changes and differences in perceptual wellbeing and RPE were analysed using a Kruskal-Wallis test. Based on the real-world relevance of the results, magnitude based inferences were used to assess the meaningfulness of any differences. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x between subject standard deviation. Based on 90% confidence intervals , the thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; >99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large, respectively [176]. Data are reported as means ± standard deviation (SD); the significance level was set at $p<0.05$.

5.4.4 Results

5.4.4.1 Match Activity Profiles

5.4.4.1.1 Playing Standard and Activity Profiles

There were a number of differences in match activity profiles between the high- and low-standard playing groups (Table 5.5). The greatest differences were seen in absolute workloads across the 5 games, primarily due to the high-standard players completing more playing minutes. Despite this, there was still greater relative distance ($p = 0.05$) covered at both high ($p = 0.224$) and moderate speeds ($p = 0.02$) in the high-standard group, more frequent collisions ($p = 0.019$) and RHIE bouts ($p = 0.004$), and greater internal loads highlighted by session-RPE ($p = 0.001$). High-standard players covered significantly greater distances on the Yo-Yo IRT ($p = 0.001$; Table 5.5). When match speed ($m.min^{-1}$) was expressed relative to maximal Yo-Yo IRT speed, there was no difference in match intensity ($p = 0.75$).

Table 5.5. Physical qualities and average match activity profiles across the tournament between the high- and low-standard team. †

	High-standard	Low-standard	ES	Likelihood
Playing time (min)	36 ± 6*	30 ± 8	0.85	96%, Very Likely
Distance covered (m)	3327 ± 588*	2516 ± 720	1.24	100%, Almost Certain
Relative distance ($m \cdot min^{-1}$)	90 ± 7*	85 ± 7	0.71	92%, Likely
Low- speed activity (m)	2525 ± 444*	2074 ± 576	0.88	96%, Very Likely
Low-speed activity ($m \cdot min^{-1}$)	71 ± 5	69 ± 6	0.19	56%, Possibly
Moderate-speed running (m)	434 ± 115*	274 ± 94	1.52	100%, Almost Certain
Moderate-speed running ($m \cdot min^{-1}$)	13 ± 3*	9 ± 2	1.58	100%, Almost Certain
High-speed running (m)	174 ± 51*	116 ± 58	1.07	99%, Very Likely
High- speed running ($m \cdot min^{-1}$)	4.3 ± 1.1	3.8 ± 1.0	0.52	81%, Likely
Match speed *vs.* Yo-Yo speed (%)	34 ± 3	34 ± 3	0.05	25%, Unlikely
Collisions				
Total (no.)	15 ± 7*	9 ± 3	1.30	100%, Almost Certain
Total (no./min)	0.4 ± 0.2*	0.3 ± 0.1	0.72	76%, Likely
Repeated High-Intensity Efforts				
Bouts (no.)	3.2 ± 1.8*	1.3 ± 0.6	1.43	100%, Almost Certain
Bout frequency (no./min)	1 every 17 min*	1 every 23 min	0.62	85%, Likely
Internal Loads				
RPE (AU)	4.3 ± 1.5*	3.1 ± 0.7	1.06	98%, Very Likely
Session RPE (AU)	180 ± 39*	109 ± 37	1.90	100%, Almost Certain
Physical Qualities				
Yo-Yo IRT (m)	1420 ± 337	922 ± 227	1.73	100%, Almost Certain

† Low-speed activity = 0-3.5 $m \cdot s^{-1}$; Moderate-speed running = 3.6-5.0 $m \cdot s^{-1}$; High-speed running = ≥5.1 $m \cdot s^{-1}$. RPE = rating of perceived exertion; Session RPE = playing time x RPE; Yo-Yo IRT = Yo-Yo intermittent recovery test level 1. ES = Effect size, 0.20-0.60, 0.61-1.19, and >1.20 were considered small, moderate and large respectively. Likelihoods ≥75% are classified as practically meaningful. * Denotes a statistically significant difference ($p < 0.05$) between playing standards.

5.4.4.1.2 Physical Fitness and Activity Profiles

When players from both the high- and low-standard teams were divided into low- and high-fitness groups, there were further differences in physical match performance variables (Table 5.5). High-fitness players covered more metres per minute of match-play across both playing standards and had greater internal loads. High-standard/high-fitness players covered greater distances than all other groups primarily through increased distance covered at moderate speeds ($p = <0.05$). In addition, they engaged in more collisions per minute and RHIE bouts ($p = <0.05$). Whilst there were a number of differences between high-standard fitness groups, the differences between high- and low-fitness groups were not as great in the low-standard playing group with only moderate differences in relative distance, primarily achieved by greater relative distances covered at low- and moderate speeds, and higher internal loads in the high-fitness group. When match speed (m/min^{-1}) was expressed relative to maximal Yo-Yo IRT speed, the high-fitness groups maintained a greater relative intensity across the tournament (high-standard: ES = 0.61; Likelihood = 77%, Likely; low-standard: ES = 0.22; Likelihood = 52%, Possibly). The high-standard/high-fitness playing group covered more metres on the Yo-Yo IRT than the low-standard/high fitness group (ES = 3.88; Likelihood = 100%, Almost Certain). Both high-standard/high fitness and high-standard/low-fitness players had greater session-RPE loads across the competition compared with both low-standard groups ($p = 0.001$).

Table 5.6. Physical qualities and average match activity profiles across the tournament between the high- and low-fitness groups across high- and low-playing standards. †

	High-standard			Low-standard		
	High-Fitness	Low-Fitness	ES	High-Fitness	Low-Fitness	ES
Playing time (min)	38 ± 3	33 ± 4	1.41	31 ± 10	30 ± 7	0.16
Distance covered (m)	3541 ± 278*	2943 ± 735	1.08	2716 ± 928	2455 ± 478	0.35
Relative distance ($m \cdot min^{-1}$)	92 ± 6	88 ± 6	0.73	88 ± 2	83 ± 6	1.04
Low- speed activity (m)	2642 ± 318	2275 ± 537	0.83	2218 ±752	2007 ± 407	0.35
Low-speed activity ($m \cdot min^{-1}$)	70 ± 6	70 ± 3	0.04	72 ± 3	68 ± 6	0.69
Moderate-speed running (m)	503 ± 106*	349 ± 104	1.46	302 ± 88	258 ± 49	0.62
Moderate-speed running ($m \cdot min^{-1}$)	13 ± 3*	11 ± 2	0.99	10 ± 2	9 ± 2	0.36
High-speed running (m)	183 ± 41	149 ± 53	0.74	119 ± 56	117 ± 67	0.03
High- speed running ($m \cdot min^{-1}$)	4.5 ± 1.1	4.0 ± 1.0	0.45	3.8 ± 0.8	3.8 ± 1.3	0.05
Match speed *vs.* Yo-Yo speed (%)	35 ± 3	33 ± 2	0.61	35 ± 2	34 ± 3	0.22
Collisions						
Total (no.)	19 ± 6*	13 ± 7	1.24	10 ± 3	9 ± 3	0.35
Total (no./min)	0.5 ± 0.2	0.4 ± 0.1	0.85	0.3 ± 0.1	0.3 ±0.1	0.19
Repeated High-Intensity Efforts						
Bouts (no.)	4 ± 2*	3 ± 1	0.79	1 ± 1	1 ± 1	-0.23
Bout frequency (no./min)	1 every 14 min	1 every 16 min	0.26	1 every 24 min	1 every 22 min	-0.27
Internal Loads						
RPE (AU)	4.6 ± 1.6	4.7 ± 0.7	-0.02	2.7 ± 0.6	2.6 ± 0.5	0.24
Session RPE (AU)	196 ± 31	174 ± 37	0.65	116 ± 22	100 ± 27	0.64
Physical Qualities						
Yo-Yo IRT (m)	1700 ± 119	1233 ± 304	2.02	1089 ± 188	785 ± 155	1.76

† Low-speed activity = 0-3.5 $m \cdot s^{-1}$; Moderate-speed running = 3.6-5.0 $m \cdot s^{-1}$; High-speed running = ≥5.1 $m \cdot s^{-1}$. RPE = rating of perceived exertion; Session RPE = playing time x RPE; Yo-Yo IRT = Yo-Yo intermittent recovery test level 1. ES = Effect size, 0.20-0.60, 0.61-1.19, and >1.20 were considered small, moderate and large respectively. * Denotes a statistically significant difference ($p < 0.05$) between high- and low-fitness groups.

5.4.4.2 Fatigue

5.4.4.2.1 Playing Standard and Fatigue

There was little difference in the fatigue responses between the high- and low-standard players across the course of the competition (Figure 5.9). There were significant reductions in CMJ power over the competition ($p = 0.004$) which peaked on day 2, but only small differences (ES = 0.21 to 0.50; $p = 0.581$) between high- and low-standard players (Figure 5.9A). Blood CK increased over the competition ($p = 0.01$), peaking on day 2 in both playing groups (Figure 5.7C). There was a greater overall increase across the competition in the low-standard players (76 ± 94% *vs.* 113 ± 81%; ES = 0.83, Likelihood = 76%, Likely; $p = 0.078$), as well as moderately greater increases on day 2 (ES = 0.74, Likelihood = 89%, Likely; $p = 0.012$) and day 4 (ES = 0.84, Likelihood = 99%, Very likely; $p = 0.015$). There were significant reductions in perceived wellbeing over the competition (Figure 5.9B [$p = 0.001$]), which was similar between the high- and low-standard players (-14 ± 17% *vs.* -17 ± 9%; ES = 0.40, Likelihood = 71%, Possibly), with no significant difference between playing standards on any day of the competition.

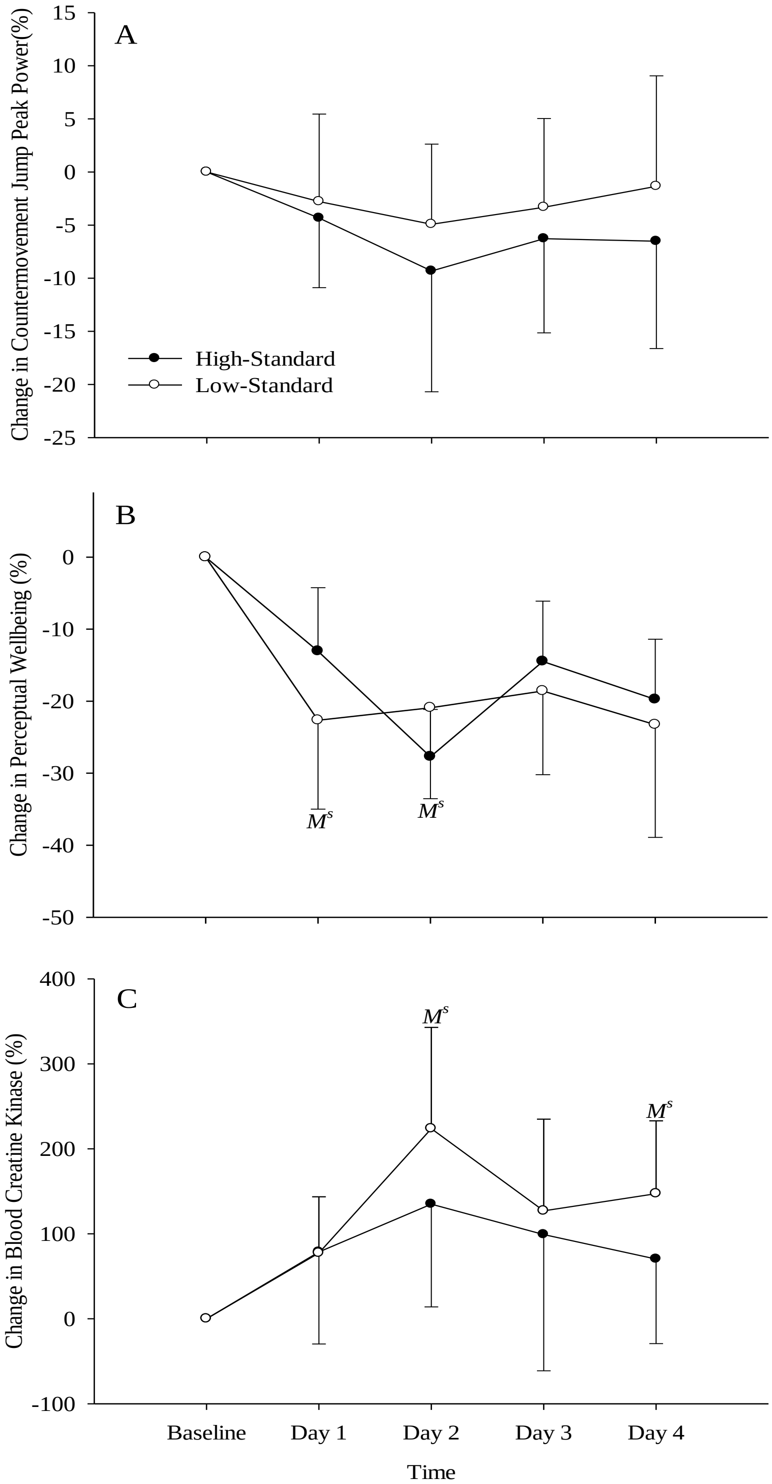

Figure 5.9. Changes in (A) countermovement jump peak power, (B) perceptual wellbeing, and (C) blood creatine kinase between the high- and low-standard playing groups over the course of the intensified competition. * Denotes a moderate effect size difference (0.60-1.20) between the high- and low-standard playing groups.

5.4.4.3 Physical Fitness and Fatigue

5.4.4.3.1 Neuromuscular Fatigue

There were reductions in CMJ power (ES = -0.75 to -2.37; p = 0.052) for each group over the competition (Figure 5.10A); these reductions were smallest in the two high-fitness groups from both playing standards (p = 0.340), with moderately greater reductions in CMJ power in the high-standard/low-fitness group compared with the high-standard/high-fitness group (ES = 0.74; Likelihood = 85%, Likely). In the high-standard group, there were greater reductions in CMJ power in the low-fitness players on day 1 (ES = 1.21; Likelihood = 100%, Almost certain) and day 3 (ES = 0.71; Likelihood = 82%, Likely). In the low-standard playing group, there was a similar, albeit less pronounced trend, with smaller reductions in CMJ power in the high-fitness group (ES = -0.41; Likelihood = 66%, Possibly).

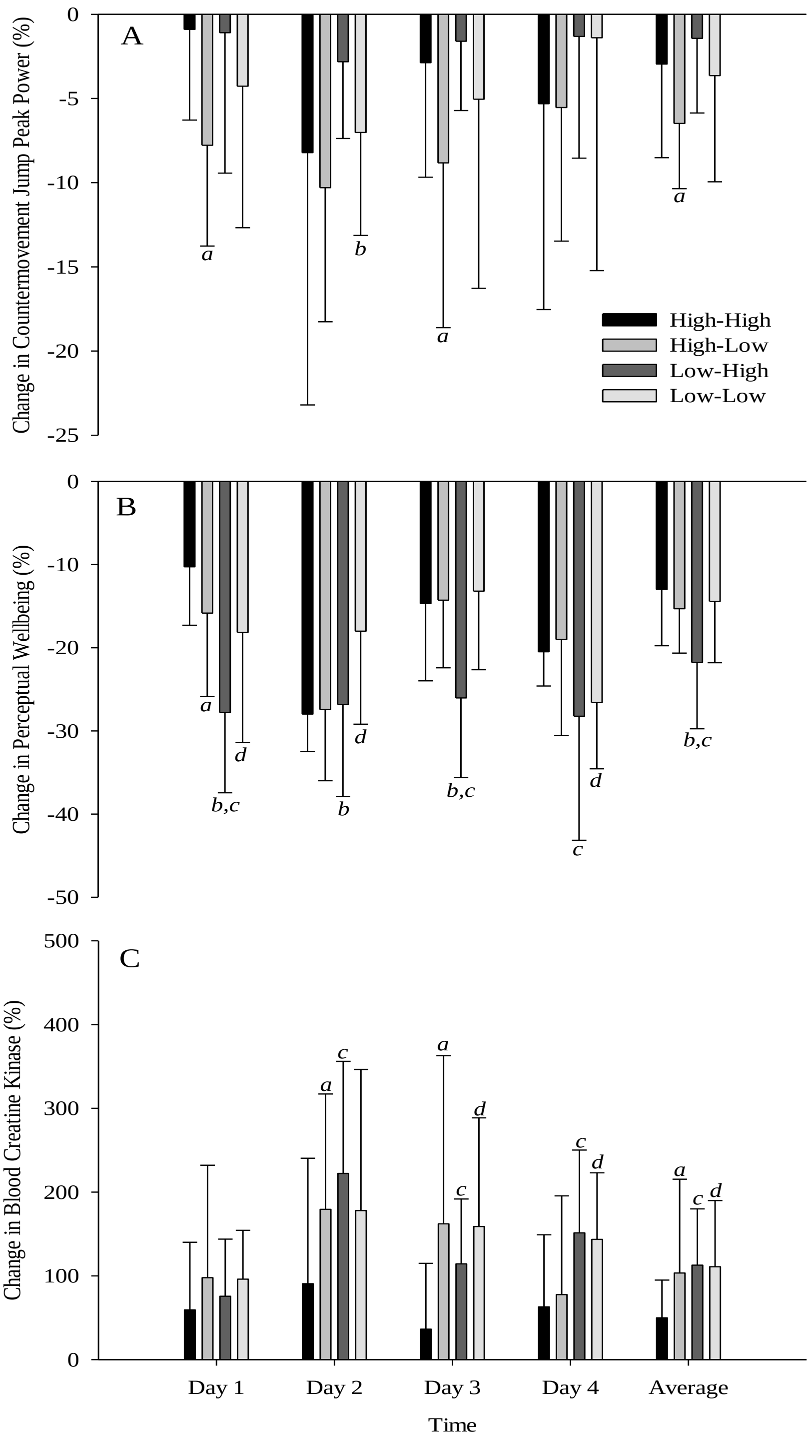

Figure 5.10. Competition changes in (A) countermovement jump peak power, (B) perceptual wellbeing, and (C) blood creatine kinase with players divided into low- and high-fitness groups. High-High = High-standard/high fitness; High-Low = High-standard/low fitness; Low-High = Low-standard/high fitness; Low-Low = Low-standard/low fitness. *a, b, c, and d* Denotes a moderate to large effect size difference to High-High.

5.4.4.3.2 Blood Creatine Kinase

There were increases in CK across the entire tournament for all groups (p = 0.001), although the smallest increases were seen in the high-standard/high-fitness group (Figure 5.10C). Compared with the high-standard/high-fitness group, there were moderately greater increases in blood CK in all other groups across the competition (high-standard/low-fitness group: ES = 0.63; Likelihood = 76%, Likely; p = 0.260; low-standard/high-fitness group: ES = 1.10; Likelihood = 90%, Likely; p = 0.623; low-standard/low-fitness group: ES = 0.95; Likelihood = 87%, Likely; p = 0.619). On day 2 and 3 of the competition, there was a greater increase in CK in the high-standard/low-fitness group (Day 2, ES = 0.62; Likelihood = 77%, Likely; Day 3, ES = 0.83; Likelihood = 86%, Likely), the low-standard/high-fitness group (Day 2, ES = 0.93; Likelihood = 90%, Likely; Day 3, ES = 1.00; Likelihood = 92%, Likely), and the low-standard/low fitness group (Day 3, ES = 1.14; Likelihood = 94%, Likely). On day 4 of the competition, there were greater increases in CK in both low-standard groups (High-fitness: ES = 0.95; Likelihood = 94%, Likely; Low-fitness: ES = 0.97; Likelihood = 92%, Likely).

5.4.4.3.3 Perceptual Wellbeing

There were reductions in perceptual wellbeing (p = 0.03) in each group over the course of the competition (Figure 5.10B). The greatest reductions were seen in the low-standard/high-fitness group, with similar reductions seen amongst the other groups. On day 1, there were smaller reductions in the high-standard/high-fitness group in comparison to all other groups. On day 2, there were smaller reductions in the low-standard/low-fitness group, with similar reductions amongst the other groups. On day 3, there was some recovery in perceptual wellbeing in all groups except the low-standard/high-fitness group. On day 4, there was little change in the two high-standard playing groups, but there were larger reductions in the low-standard playing groups.

5.4.5 Discussion

This study compared the fatigue responses to intensified junior rugby league competition between playing standards. In addition, the influence that physical fitness had on the fatigue response and match activity profiles was also investigated. Our hypotheses were partially confirmed, with greater playing intensity in the high-standard playing group, but little difference in fatigue responses between playing standards, although there was greater increases in blood CK in the low-standard playing group. Our second hypothesis was also partially confirmed with smaller increases in fatigue and blood CK as physical fitness increased despite greater playing intensities. As playing standard increases, so too do the physical demands of competition [60], although this does not appear to translate to increased player fatigue. Higher physical fitness is associated with greater playing intensity during an intensified competition and reduced post-match fatigue and markers of muscle damage.

The high-standard playing group had greater physical fitness than the low-standard group, highlighted by these players covering more metres on the Yo-Yo IRT. This is in accordance with previous research that has shown that as playing standard increases, so too do physical qualities [73, 91]. Elevated physical fitness appeared to translate to increases in absolute and relative match workloads. High-standard players covered more metres per minute of match-play, which was primarily achieved through greater moderate-speed running. Despite these greater match intensities in the high-standard playing group, when match speed was expressed relative to maximal speed on the Yo-Yo IRT, there was no difference in playing intensity between groups. This suggests that the match speeds in both the high- and low-standard competitions would have placed a similar relative physiological stress on players. On the other hand, the greater internal loads experienced by the high-standard players (highlighted by RPE and session-RPE) is suggestive of greater physiological strain during the competition. This could be explained by the increased number of physical collisions and RHIE bouts performed by the high-standard group, which are overlooked by simply assessing match running intensities. Both collisions and RHIE bouts are extremely demanding tasks, both physically and mentally [9, 20], and therefore could explain the increased internal loads in the high-standard playing group. These results clearly indicate that as playing standard increases so too does physical fitness which appears to translate to increases in playing intensity [24, 60]. In addition, only assessing the running demands of the game clearly underestimates the physiological loads placed on players.

When players were divided into high-fitness and low-fitness groups across both playing standards based on Yo-Yo IRT performance, there were some differences in absolute and relative playing intensities. In the high-standard group, there was a larger disparity between the high- and low-fitness groups in terms of match workloads. High-fitness players had greater playing minutes, covering more absolute and relative distance, primarily achieved through increased moderate-speed running. The match speeds performed in the high-fitness group were at a greater intensity relative to maximal Yo-Yo speed. In addition, these players were involved in more collisions and RHIE bouts over the tournament. The differences in the low-standard playing group were less pronounced, with high-fitness players covering more metres per minute, primarily achieved through increased low-speed activity. The large differences in physical performance observed in the high-standard group and smaller differences observed in the low-standard group may be explained by the Yo-Yo IRT scores for each group. In the high-standard players, there was a larger absolute difference in Yo-Yo IRT scores between the high- and low-fitness groups than in the low-standard players. As such, maximising absolute high-intensity running ability, and introducing minimum standards, would be useful in order to maintain performances across the entire playing group.

Despite the increased absolute external and internal loads in the high-standard playing group, there were similar increases in fatigue and markers of muscle damage across the competition between playing standards. These increases in fatigue and markers of muscle damage were greatest over the first 2 days of the competition in both groups when players were involved in 2 games on each day. This suggests that physical fitness may offer some protective effect against fatigue and markers of muscle damage, which is in accordance with previous research [139]. Although there were greater reductions in CMJ power in the high-standard group, these differences were small in magnitude, and did not reach the threshold of practical importance [174]. The similar changes in lower-body fatigue between the high- and low-standard teams may be indicative of the similar match speeds relative to maximal Yo-Yo IRT. However, there were smaller increases in blood CK in the high-standard playing group, particularly at the end of days 2 and 4 of the competition. This result is even more significant given that the high-standard playing group were involved in 40% more collisions over the tournament, which are directly linked to elevations in CK [47]. There were also similar reductions in perceptual wellbeing over the competition between the playing standards. Despite greater absolute workloads in the high-standard playing group, there was little difference in the fatigue responses and smaller increases in blood CK, across the tournament. This may be due to increased physical fitness in the high-standard playing group. In addition, expressing match speeds in relation to maximal Yo-Yo IRT speed may be a useful metric for determining the relative stress placed on each individual player by the running component of match-play.

The protective effects of physical fitness on muscle function and to some extent muscle damage are clear when players were divided into low- and high-fitness groups. Despite greater match speeds in relation to maximal Yo-Yo IRT speed as well as absolute workloads, the high-fitness players in both playing standards exhibited the smallest reductions in CMJ power across the tournament. Previous research has suggested that players with well-developed high-intensity running ability possess greater eccentric strength and the ability to utilise the stretch-shortening cycle [49] which may result in less muscle fatigue [139]. High-fitness only appeared to reduce muscle damage in the high-standard group. This group had significantly greater Yo-Yo IRT performance than the low-standard/high-fitness players (1700 ± 119 *vs.* 1089 ± 188 m) which may suggest that irrespective of playing intensity, there is a base level of fitness required before muscle damage is reduced through increased fitness. Once again, these high-fitness players performed more collisions than their less-fit counterparts, clearly highlighting the protective effect of well-developed physical fitness to elevations in blood CK [139]. There was little difference in perceptual wellbeing between groups, although the low-standard/high-fitness group had greater reductions across the competition. Taken together, well-developed physical fitness appears to reduce post-match fatigue and increase match playing intensities. As such, coaching staff should aim to maximise fitness prior to intensified competition in order to minimise post-match fatigue.

While this study adds to the body of literature on fatigue in team sport players, our findings are not without their limitations. Only Yo-Yo IRT performance was assessed as a measure of physical fitness. Previous research indicates that lower-body strength also impacts on post-match fatigue [139]. Therefore, it is likely that other physical qualities, such as muscular strength, may influence the fatigue response seen following intensified competition. In addition, data collection ceased immediately following the competition. As such, it is unknown whether the recovery time-course differed between groups. Future research addressing these points is warranted.

5.4.6 Conclusions

This study highlighted that as playing standard increases in junior rugby league players, so too does the intensity of match-play. Well-developed high-intensity running ability appears to be associated with greater absolute and relative internal and external workloads during competition. Despite increased workloads in players with well-developed physical qualities, these players experienced smaller increases in blood CK and less pronounced reductions in muscle function. As such, increasing fitness in junior players may be one of the most effective strategies for minimising accumulations in post-match fatigue and markers of muscle damage during intensified rugby league competition. Intensified competitions are always likely to occur in junior rugby league and numerous other team sports. Therefore, players should be exposed to demanding training prior to participating in tournaments in an attempt to increase physical fitness and gain a degree of protection against post-match fatigue.

5.4.7 Practical Applications

- Increased physical fitness result in greater relative and absolute match workloads.
- Increased physical fitness results in less fatigue and muscle damage during an intensified competition.
- Coaching staff should aim to maximise physical fitness in order to optimise match performance and reduce player fatigue.

5.4.8 Acknowledgements

The authors would like to thank the players and coaching staff from St. Thomas More and Padua College for volunteering to take part in the study as well as the organising committee of the Confraternity Shield. No external funding was used in this study; Rich Johnston, Tim Gabbett, and David Jenkins have no conflicts of interest to declare.

5.5 Study 9: The effect of different repeated high-intensity effort bouts on subsequent running, skill performance and neuromuscular function

This study has been accepted for publication following peer review. Full reference details are:

Johnston RD, Gabbett TJ, Jenkins DG, and Speranza, MJ. The effect of different repeated high-intensity effort bouts on subsequent running, skill performance and neuromuscular function. *Int J Sports Physiol Perform, in press*, 2015.

5.5.1 Abstract

The purpose of this study was to assess the impact of different repeated high-intensity effort (RHIE) bouts on player activity profiles, skill involvements and neuromuscular fatigue during small-sided games. Twenty-two semi-professional rugby league players (age 24.0 ± 1.8 years; body mass 95.6 ± 7.4 kg) participated in this study. During 4 testing sessions, players performed RHIE bouts that each differed in the combination of contact and running efforts, followed by a 5 min 'off-side' small-sided game before performing a second bout of RHIE activity and another 5 min small-sided game. Global positioning system microtechnology and video recordings provided information on activity profiles and skill involvements. A countermovement jump and a plyometric push-up assessed changes in lower- and upper-body neuromuscular function after each session. Following running dominant RHIE bouts, players maintained running intensities during both games. In the contact dominant RHIE bouts, reductions in moderate-speed activity were observed from game 1 to game 2 (ES = -0.71 to -1.06). There was also moderately lower disposal efficiencies across both games following contact dominant RHIE activity compared with running dominant activity (ES = 0.62-1.02). Greater reductions in lower-body fatigue occurred as RHIE bouts became more running dominant (ES = -0.01 to -1.36), whereas upper-body fatigue increased as RHIE bouts became more contact dominant (ES = -0.07 to -1.55). Physical contact causes reductions in running intensities and the quality of skill involvements during game-based activities. In addition, the neuromuscular fatigue experienced by players is specific to the activities performed.

Key Words: Team sport; rugby league; movement demands; pacing; global positioning system; fatigue

5.5.2 Introduction

Collision based team sports such as rugby league and rugby union are characterised by high-intensity running and contact efforts interspersed with periods of lower-intensity activity [2, 207]. Whilst the majority of match-play is spent performing low-intensity activities [2], high-intensity activities typically occur at critical periods and often in close proximity to one another [25, 76]. These intense bouts of activity have been termed repeated high-intensity effort (RHIE) bouts [76]. Specifically, a RHIE bout involves 3 or more contact, acceleration, or high-speed running efforts with less than 21 seconds between each effort [4]. Although 3 efforts is the minimum number required to constitute a RHIE bout, these bouts can be much more frequent and longer in duration [208, 65]. The longest RHIE bout reported in a study of elite rugby league players included 13 efforts (4 contact and 9 acceleration) over a 120 s period with an average recovery time of 5 s between efforts [65]. Not only do these RHIE bouts occur frequently during rugby league [65, 25] and union competition [208], they also tend to occur during critical periods of play such as when defending the try-line [25]. Moreover, winning teams perform more RHIE bouts, more efforts per bout, and maintain a higher playing intensity whilst recovering from high-intensity efforts [55]. Clearly, the frequency of RHIE bouts and the critical time points at which they occur suggests players must have the capacity to maintain physical, technical and decision-making performance following these efforts in order to deliver successful outcomes.

Previous research has highlighted that the addition of contact efforts to repeated-sprints [9] and small-sided games [20, 209, 210] leads to greater reductions in running performance and increases in perceived effort compared with activities involving running alone [20, 9]. Not only does physical contact result in transient fatigue, residual fatigue is also apparent, with increases in upper-body fatigue and muscle damage following contact small-sided games [47]. Conversely, increased running loads result in greater increases in lower-body fatigue [47]. Whilst previous studies have highlighted reductions in running following ‘contact only’ RHIE bouts [210, 209], players from both rugby codes rarely perform contact in isolation during match-play, rather they are interspersed with running efforts [65, 208]. Therefore, it is important to determine whether subsequent running activity and fatigue is influenced by the type of RHIE bout performed (i.e. contact or running dominant).

Although physical performance is important [211], skill and technical performance is inextricably linked to game success [212]. One study demonstrated that adjustables showed reductions in the frequency and quality of skill involvements following the most intense 5 min running period during elite rugby league games [77]. In addition, tackle technque appears reduced following RHIE bouts [84]. Despite this, the specific effect RHIE bouts have on skill performance and whether this is dependent on the type of RHIE bout performed remains unknown. Given that RHIE bouts often occur during vital passages of play [25], it is important to investigate the impact of RHIE bouts on both physical and technical performance. This would allow coaches to develop specific repeated effort drills that would develop players' ability to maintain skills under pressure and fatigue. With this in mind, the aims of this study were to determine the impact of different RHIE bouts on (1) running intensities (2) skill involvements and (3) neuromuscular fatigue during small-sided games. It was hypothesised that increasing the contact demands of the RHIE bouts would result in greater reductions in running intensity and more upper-, but less lower-body fatigue. In addition, skill performance would be negatively impacted by performing RHIE bouts.

5.5.3 Methods

5.5.3.1 Design

In order to test our hypotheses, a counter-balanced, cross-over experimental design was used. Players took part in 4 different RHIE bouts followed by small-sided games over 21 days; each session was separated by 7 days. Players wore global positioning system (GPS) microtechnology units during the RHIE bouts and small-sided games in order to provide information on activity profiles. Additionally, each small-sided game was filmed to assess the quality and frequency of skill involvements.

5.5.3.2 Subjects

Thirty-eight semi-professional rugby league players (age 24.2 ± 2.3 years; body mass 96.1 ± 10.9 kg) from the same Queensland Cup club, participated in the study. Data were collected during weeks 9-11 of the pre-season period, with players free from injury. Over the course of the testing period, players were asked to maintain their normal diet. In accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), players received an information sheet outlining experimental procedures; written informed consent was obtained from each player. The study was approved by the University's ethical review board for human research. Over the course of the study, some players were unavailable for each testing session. Only players that completed each of the 4 conditions were used within the analysis. Therefore, 22 players (age 24.0 ± 1.8 years; body mass 95.6 ± 7.4 years) formed the final cohort for this study.

5.5.3.3 Protocol

On each of the 4 testing sessions, players performed 3 RHIE bouts followed by a standardised 5 minute 'off-side' small-sided game before repeating the RHIE bouts and small-sided game (Figure 5.11). Within 30 min following the RHIE bouts and games, neuromuscular function was assessed via a countermovement jump (CMJ) and plyometric push-up (PP). Players trained in two separate squads with one squad performing the testing first, immediately followed by the second squad of players. Prior to the first session, each squad was divided into two teams of nine players, ensuring an even spread of playing positions. Whilst every attempt was made to maintain the makeup of the teams across each of the 4 conditions, due to player absences (e.g. injury, separate training) some variations in the players within each team did occur between conditions. The number of players on each team was maintained at 9 for each condition.

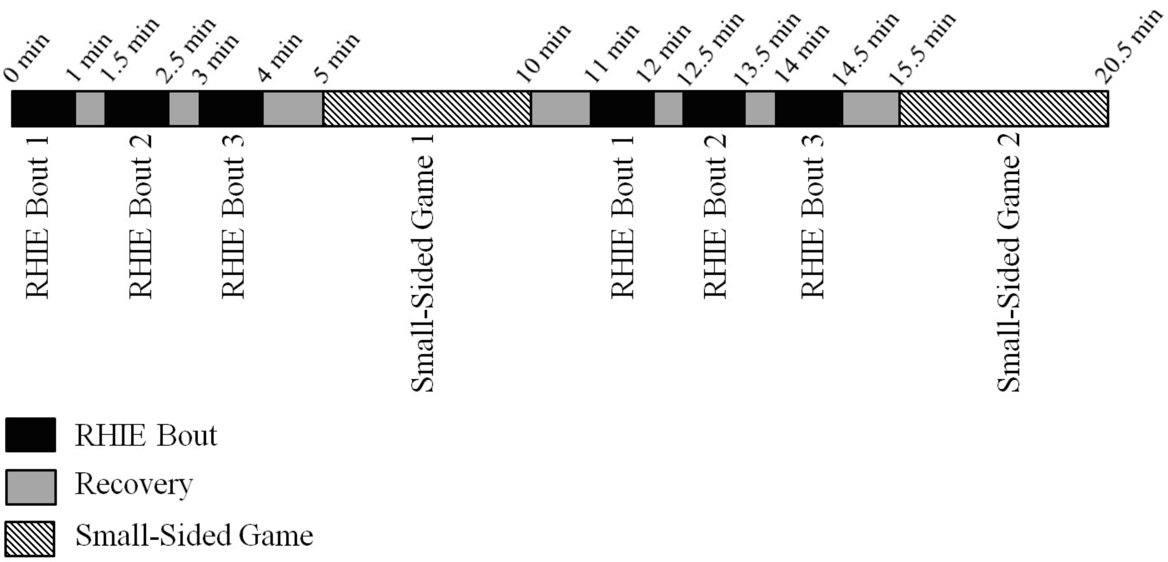

Figure 5.11. A schematic representation of the experimental protocol.

5.5.3.4 RHIE Bouts

Prior to each small-sided game, players performed 3 x 6-effort RHIE bouts. Each bout lasted for 1 minute and involved 6 efforts with 30 s recovery between each bout where players jogged 20 m at their own pace. Following the third RHIE bout and the 20 m jog, there was an additional 30 s of recovery prior to the start of the small-sided game. These bouts were designed to reflect the work-to-rest ratios of the most demanding RHIE bouts observed in competition [76, 211]. The 4 different RHIE bouts involved a combination of 5 s contact and/or 20 m sprint efforts with a 1:1 work-to-rest ratio. The 4 bouts comprised (1) 'all contact' (6 contact efforts), (2) 'all running' (6 x 20 m sprints), (3) 'mainly contact' (4 contact, 2 sprint efforts), and (4) 'mainly running' (2 contact, 4 sprint efforts) (Table 5.7). From a standing position, the contact efforts involved a hit on each shoulder, utilising over- and under-hook grips, before attempting to wrestle their opponent onto their back from a standing position. The 20 m sprint involved an all-out sprint followed by a 10 m deceleration.

Table 5.7. Activities performed during each RHIE bout preceding the small-sided games. †

RHIE Bout	**Activities**	**Order of Efforts**
All Contact	6 x 5 s contact and wrestle efforts on a 10 s cycle	C-C-C-C-C-C
All Running	6 x 20 m sprints on a 10 s cycle	R-R-R-R-R-R
Mainly Contact	4 x 5 s contact and wrestle efforts on a 10 s cycle 2 x 20 m sprints on a 10 s cycle	C-C-R-C-C-R
Mainly Running	2 x 5 s contact and wrestle efforts on a 10 s cycle 4 x 20 m sprints on a 10 s cycle	R-R-C-R-R-C

† RHIE = repeated high-intensity effort; R = running effort; C = contact effort.

5.5.3.5 Small-Sided Games

One minute following the third RHIE bout, the first small-sided game was played. The small-sided games were 5 min in duration and involved 9 vs. 9 players on a standardised (68 m x 40 m) floodlit grassed playing area. Unlike a regular small-sided rugby game, during 'off-side' games, the ball can be passed in any direction (i.e. to 'off-side' players). The 'off-side' game used the same rules as those reported previously [20].

5.5.3.6 Activity Profiles

Game and RHIE activity profiles were assessed using GPS microtechnology devices. The GPS units sampled at 10 Hz (Optimeye S5, Catapult Sports, VIC, Australia) and included a

100 Hz tri-axial accelerometer and gyroscope to provide information on collisions. Data were downloaded to a laptop and subsequently analysed (Sprint, Version 5.1.1, Catapult Sports, VIC, Australia). Data were categorised into low-speed activity (0-3.5 $m \cdot s^{-1}$), moderate-speed running (3.6-5.0 $m \cdot s^{-1}$) and high-speed running (≥5.1 $m \cdot s^{-1}$) [2]. Player Load™ Slow (<2 $m \cdot s^{-1}$) was used to determine the load associated with the non-running components (i.e. physical contact) of the RHIE bouts [167]. These units offer valid and reliable estimates of activities common in team sports [164, 160]. To assess internal load of each condition, within 30 min following the session, rating of perceived exertion (RPE [CR-10]) was recorded for each player [205].

5.5.3.7 Skill Involvements

Each small-sided game was filmed using a video camera (Cannon Legria HV40, Japan). Games were manually coded by a trained operator for number of possessions, number and quality of disposals, and number of errors. An effective disposal was classified as a completed pass to a team-mate in an 'open' position; an ineffective disposal involved a pass that went to a closely marked team-mate or the ball was turned over [213]. Disposal efficiency represented the number of effective passes divided by the total number of possessions. An error was coded when the ball went to ground, or was intercepted. The test re-test reliability (typical error of measurement [TE]) was determined by the same operator coding two games on two separate occasions, 4 weeks apart for number of possessions (TE = 3.2%), number of disposals (TE = 5.7%), quality of disposals (TE = 4.3%), and percentage of errors (TE = 9.9%).

5.5.3.8 Neuromuscular Fatigue

Neuromuscular fatigue was assessed within 15 min after the second game. Lower-body neuromuscular fatigue was assessed using a CMJ; upper-body neuromuscular fatigue was assessed using a PP as described previously [30]. Both exercises were performed on a force platform (Kistler 9290AD Force Platform, Kistler, USA) connected to a laptop running manufacturer designed software (QuattroJump, Kistler, USA). Changes in neuromuscular fatigue were compared against each player's maximum value that was determined 5 days prior to the first testing session. Maximum peak power was determined by their highest score from 3 CMJ's and PP's performed in a non-fatigued state, with approximately 5 min between efforts. The between day TE for the CMJ and PP was 3.5% and 3.8% for peak power, respectively.

5.5.3.9 Statistical Analysis

Based on the real-world relevance of the results, magnitude based inferences were used to determine the meaningfulness of any differences in activity profile, skill, and neuromuscular fatigue changes during and following the different RHIE bouts and games. Firstly, the likelihood that changes in the dependent variables were greater than the smallest worthwhile change was calculated as a small effect size of 0.20 x the between subject standard deviation. Thresholds used for assigning qualitative terms to chances were as follows: <1% almost certainly not; <5% very unlikely; <25% unlikely; <50% possibly not; >50% possibly; >75% likely; >95% very likely; ≥99% almost certain [174]. The magnitude of difference was considered practically meaningful when the likelihood was ≥75%. Secondly, magnitudes of change in the dependent variables were assessed using Cohen's effect size (ES) statistic [175]. Effect sizes (ES) of 0.20-0.60, 0.61-1.19, and ≥1.20 were considered small, moderate and large respectively [176]. Data are reported as means ± SD.

5.5.4 Results

5.5.4.1 RHIE Bouts

Players covered an average of 43 ± 2 $m{\cdot}min^{-1}$ in the 'all contact', 49 ± 2 $m{\cdot}min^{-1}$ in the 'mainly contact', 84 ± 4 $m{\cdot}min^{-1}$ in the 'mainly running', and 105 ± 7 $m{\cdot}min^{-1}$ in the 'all running' RHIE bouts (ES = 3.00-12.97). In addition, Player Load™ Slow values per minute of each bout were 7.6 ± 1.7 $AU{\cdot}min^{-1}$ ('all contact'), 5.0 ± 1.0 $AU{\cdot}min^{-1}$ ('mainly contact'), 4.0 ± 1.0 $AU{\cdot}min^{-1}$ ('mainly running'), and 2.6 ± 0.5 $AU{\cdot}min^{-1}$ ('all running') (ES = 1.77-3.99).

5.5.4.2 Game Intensities

In game 1, there were similar running intensities in each condition other than the 'all running' condition where the relative intensity was moderately lower than the 'all contact' (ES = -0.69

± 0.22; likelihood = 93%, likely) and ‘mainly contact’ (ES = -0.69 ± 0.43; likelihood = 89%, likely) conditions (Figure 5.12). There was little difference between the relative intensities of game 2 for the different conditions. From game 1 to 2, there were only small and trivial reductions in the ‘mainly running’ (ES = -0.36 ± 0.62; likelihood = 83%, likely) and ‘all running’ (ES = -0.17 ± 0.23; likelihood = 87%, likely) conditions. There were however larger, moderate reductions in relative intensity in game 2 in the ‘all contact’ (ES = -0.96 ± 0.42; likelihood = 94%, likely) and ‘mainly contact’ (ES = -1.07 ± 0.34; likelihood = 94%, likely) conditions. These reductions were largely brought about by decreases in moderate-speed activity in game 2 in the ‘all contact’ (ES = -0.71 ± 0.34; likelihood = 93%, likely) and ‘mainly contact’ (ES = -1.06 ± 0.48; likelihood = 89%, likely) conditions. Albeit small, there were greater relative distances covered in game 2 of the ‘mainly running’ condition compared to all other conditions (ES = 0.34-0.38).

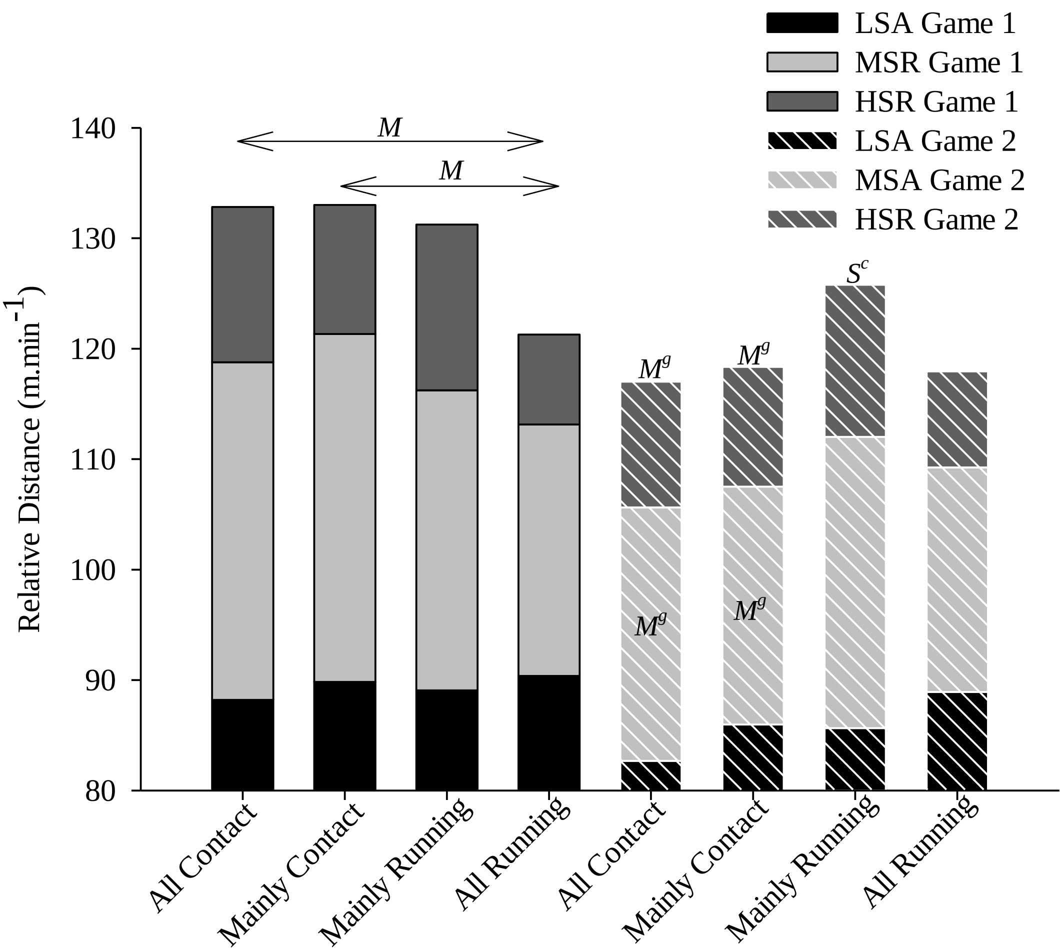

Figure 5.12. Movement demands of game 1 and game 2 following the different repeated effort bouts. LSA = low-speed activity; MSR = moderate-speed running; HSR = high-speed running. M^g refers to a moderate (0.61-1.19) effect size difference between game 1 and 2; S^c and M^c refers to a small (0.20-0.60) and moderate effect size difference between conditions.

5.5.4.3 Skill Involvements

During game 1, there were a total of 67, 79, 79, and 73 passes made in the 'all contact', 'mainly contact', 'mainly running', and 'all running' conditions. In game 2, there were a total of 58, 81, 66, and 73 passes made in the 'all contact', 'mainly contact', 'mainly running', and 'all running' conditions. There was no difference in the number of effective passes between conditions in game 1. In game 2, there were moderate increases in the number of effective passes across all conditions except in the 'all contact' condition where there was a small reduction in effective passes compared with game 1 (ES = -0.30 ± 0.22; likelihood = 77%, likely [Figure 5.13]). In game 1 there were moderately greater disposal efficiencies in the 'mainly running' (ES = 0.77-1.02) and 'all running' (ES = 0.62-0.79) conditions, compared with the games following the contact dominant conditions. There was little difference in skill performance between game 1 and game 2 in any condition although there was still greater disposal efficiencies observed in the game in the 'mainly running' (ES = 0.73 ± 0.19; likelihood = 97%, very likely), and 'all running' (ES = 0.83 ± 0.22; likelihood = 100%, almost certain) conditions compared with the 'mainly contact' condition. There were no differences in the number of errors between games or conditions.

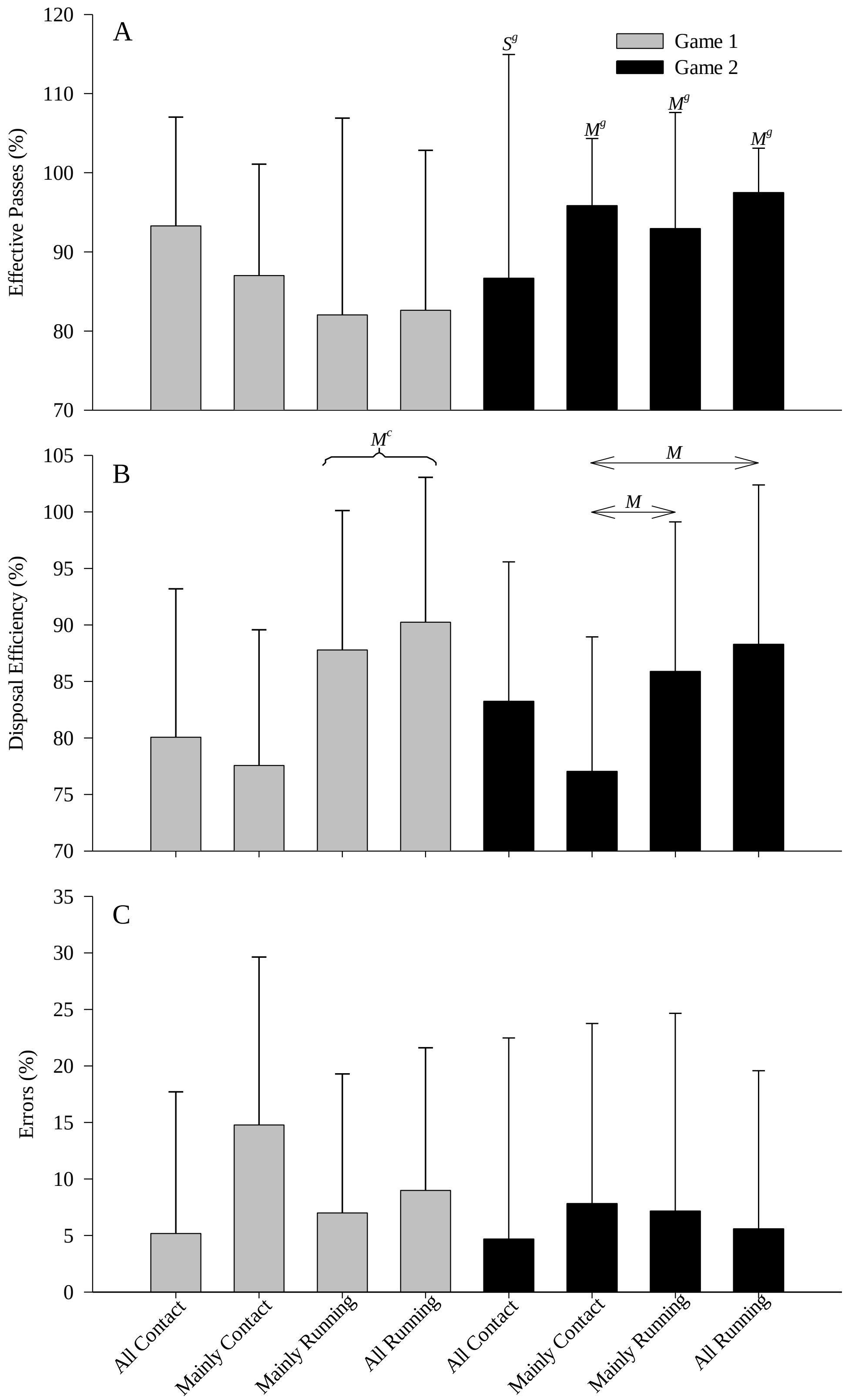

Figure 5.13. Skill performance during game 1 and 2 following the different repeated effort bouts. S^g, and M^g refers to a small (0.20-0.60) and moderate (0.61-1.19) effect size difference between game 1 and 2; M^c refers to a moderate effect size difference between conditions.

5.5.4.4 Neuromuscular Fatigue

There was no change in CMJ peak power (Figure 5.14A) following the ‘all contact’ (ES = -0.01 ± 0.11; likelihood = 29%, possibly not), small reductions following the ‘mainly contact’ (ES = -0.33 ± 0.18; likelihood = 64%, possibly), moderate reductions following the ‘mainly running’ (ES = -1.02 ± 0.21; likelihood = 79%, likely), and finally large reductions following the ‘all running’ condition (ES = -1.36 ± 0.20; likelihood = 85%, likely). Furthermore, the reductions observed following the ‘all running’ and ‘mainly running’ conditions were moderately greater than the changes following the ‘all contact’ conditions (ES = 0.68-0.85).

There were large reductions in PP peak power (Figure 5.14B) following the ‘all contact’ (ES = -1.55 ± 0.44; likelihood = 100%, almost certain) and ‘mainly contact’ (ES = -1.37 ± 0.32; likelihood = 100%, almost certain) conditions, moderate reductions following the ‘mainly running’ condition (ES = -0.92 ± 0.65; likelihood = 56%, possibly), and finally trivial reductions following the ‘all running’ condition (ES = -0.07 ± 0.09; likelihood = 36%, possibly). Reductions observed following the ‘all contact’ and ‘mainly contact’ conditions were moderately greater than the changes following the ‘all running’ (ES = 1.12-1.27) and ‘mainly running’ (ES = 0.66-0.88) conditions.

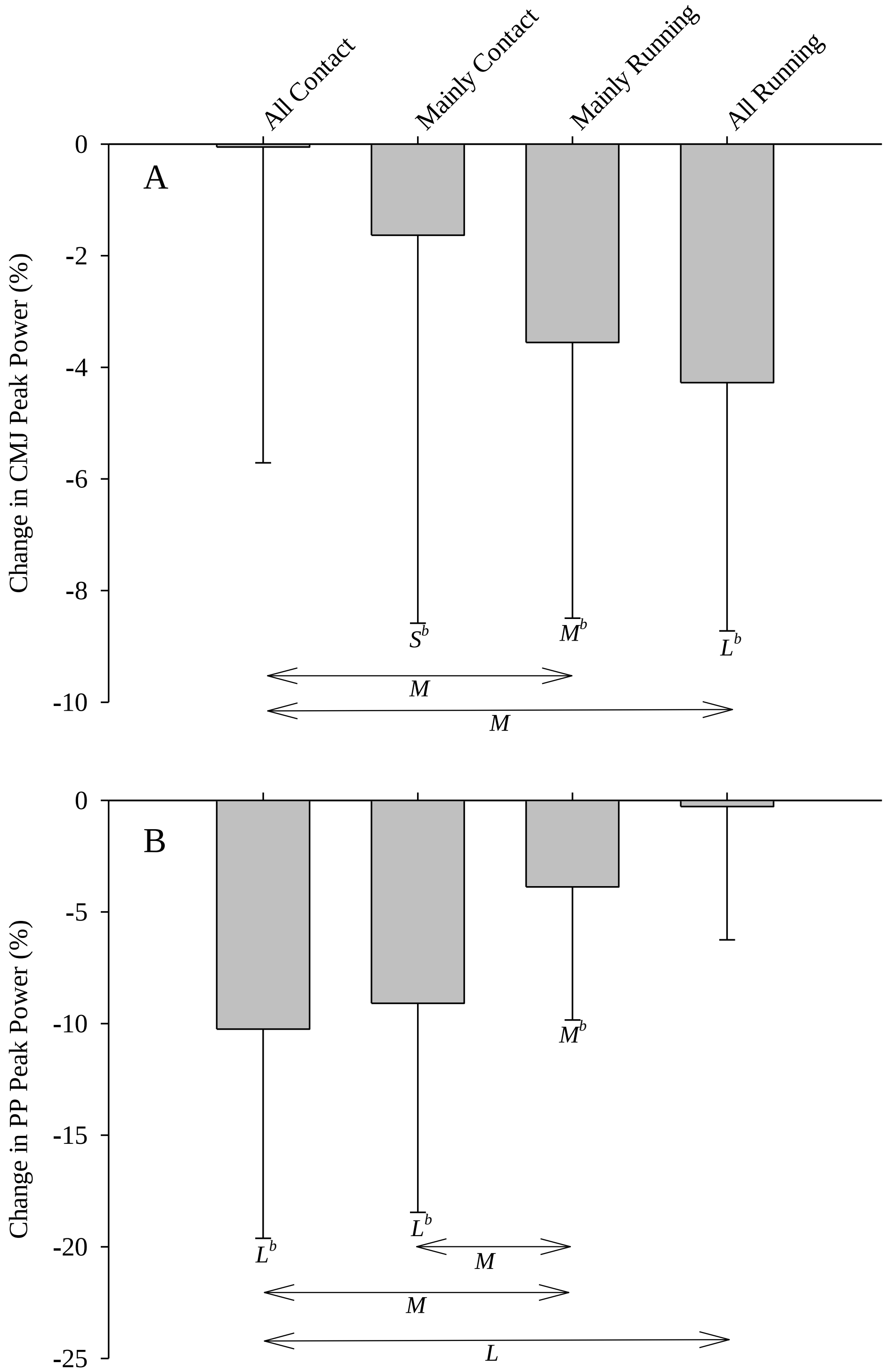

Figure 5.14. Changes in (A) lower body muscle function and (B) upper body muscle function following the different repeated effort bouts and small-sided games. CMJ = countermovement jump; PP = Plyometric push-up. S^b, M^b, and L^b refers to a small (0.20-0.60), moderate (0.61-1.19) and large (≥1.20) effect size difference from baseline; M^c and L^c refers to moderate and large effect sizes between conditions.

5.5.5 Discussion

The aims of this study were to determine the impact of different RHIE bouts on running intensities and skill involvements during game-based activities and to assess the neuromuscular fatigue response to RHIE bouts comprising different amounts of contact and sprinting. Players set a lower, but 'even-paced' pacing strategy in the 'all running' condition compared with the other conditions. When players were required to perform contact in the RHIE bouts, they began with higher running intensities in game 1, before showing reductions in game 2. These reductions were greater following the contact dominant conditions. As such, when players are required to perform contact dominant RHIE bouts they show greater reductions in running intensities compared to following running dominant RHIE activity. Furthermore, following contact dominant RHIE activity, players display lower quality skill involvements than following running dominant RHIE activity. Lower-body and upper-body fatigue appear to increase with both the running and contact demands of RHIE activity, respectively. This study demonstrates that physical contact causes greater reductions in running intensities and the quality of skill involvements during game-based activities compared with running efforts.

Different running intensities were observed during the small-sided games following the different RHIE bouts. Particularly in game 1, following the 'all running' condition, player work rates were reduced compared to the other conditions. They appeared to set an 'even-paced' pacing strategy that they could maintain across both game 1 and game 2 [214]. The reason for this reduced intensity following the 'all running' bouts may be due to players being unaccustomed to exclusively performing running efforts given the high frequency of physical collisions during match-play [2, 20]. In the other conditions, players employed a 'positive' pacing strategy whereby the playing intensity was high to begin with (i.e. in game 1) before decreasing in game 2; indicative of player fatigue [214]. These reductions in intensity were greater in game 2 following the contact dominant RHIE bouts, primarily through reductions in moderate-speed activity. These results are in accordance with others that have reported greater reductions in both high-speed [209, 9], and moderate-speed running [210] with increased contact demands. These findings clearly demonstrate the large physical cost associated with performing contact efforts. It is interesting to note that the greatest RPE was observed in the 'mainly contact' condition where players had to perform 4 contact and 2 running efforts per

RHIE bout. It is likely that combining the demanding nature of contact efforts with the cardiovascular stress of running is particularly demanding for players and resulted in a greater RPE than the other conditions. Given the intense contact demands of competition, players should be regularly exposed to RHIE bouts involving contact in order to minimise reductions in player work-rates and deliver successful performances. A combination of running and contact efforts is more game-specific and likely to elicit greater internal loads.

Other than in the ‘all contact’ condition, where small reductions were observed, players showed moderate increases in the percentage of effective passes from game 1 to game 2. There are a number of potential explanations that could explain these findings. Firstly, players may be more accustomed to their team-mates, and opposition’s style of play following game 1 allowing for improved passing performance. Secondly, a reduction in game speed, allowing players more time to make the correct decision and therefore deliver an effective pass could also have played a role. Whilst this may be the case in game 2 in the ‘mainly contact’ and ‘mainly running’ conditions, following the ‘all running’ RHIE bout, from game 1 to 2, the relative intensity was unchanged yet there was a marked increase in the percentage of effective passes. As such, an alternate explanation could be that as players were accustomed to performing this skill under pressure and fatigue, they were able to withstand higher levels of arousal, before arousal had detrimental effects on skill performance [215]. Indeed, previous research from water polo indicates that during high levels of exertion and fatigue, response accuracy on a sport-specific decision making test is increased, and shooting accuracy is maintained despite reductions in shooting technique [216]. Similarly, soccer players appear to be able to maintain skill performance over the course of a game despite reductions in physical performance and apparent fatigue [217].

There was little change in the total number of passes per player between game 1 and game 2 following any of the RHIE bouts. Collectively, these results are in contrast to previous research from rugby league that reported reductions in the number and quality of skill involvements following the peak 5 min period during match-play [77]. A reason for this disparity could be due to the nature of the games, with the current study employing ‘off-side’ games that were shorter in duration as opposed to the ‘on-side’ nature and longer duration of rugby league competition. Despite this, there was reduced disposal efficiency in the games following contact dominant RHIE bouts compared to those following the running dominant bouts. This reduced disposal efficiency was largely brought about by players being caught in possession more frequently in the games following the contact dominant RHIE bouts. Whilst speculative, this could be due to higher levels of upper-body fatigue observed currently, and previously [47], resulting in players being unable to complete fast exchanges in passes and therefore being caught in possession more frequently. Further research is required to determine the influence of RHIE activity and fatigue on technical and decision making performance in more closely controlled, sport specific 'on-side' scenarios in rugby players.

Greater increases in lower-body fatigue following the 'all running' RHIE bouts and games and progressively smaller increases in lower-body fatigue as the running loads of the RHIE bouts reduced were also observed. The opposite was observed for upper-body fatigue which increased with the contact demands. These findings are in accordance with those previously published [47] and clearly highlight that the fatigue response to players involved in contact sport is likely to be whole body in nature. Simply determining lower-body muscle fatigue is likely to underestimate the fatigue response. Furthermore, this provides useful information to coaches with players covering greater running loads during competition (i.e. outside backs) likely to experience more lower-body fatigue. Conversely, players who perform larger numbers of contact efforts (i.e. the forwards) are likely to suffer more upper-body fatigue in the days following competition. Further research should aim to elucidate specific training and recovery strategies following competition according to the activities performed by each player, based on their in-game positional demands.

It is important to note that this study was not without its limitations. Firstly, whilst we attempted to maintain the same work-to-rest ratios of 1:1 for both the 5 s contacts and the 20 m sprints in the RHIE bouts, players typically completed the 20 m sprints in 3-4 seconds, and therefore had a slightly longer rest period (6-7 seconds). Secondly, given the limited movement of either player in the wrestle efforts, they were more eccentric/isometric in nature compared to the concentric dominant running efforts, which is likely to impact fatigue symptoms. Thirdly, the placement of the unit between the shoulder blades could influence the measurement of Player Load™ and might explain some of the differences observed between the contact and running RHIE bouts [218]. The placement of the GPS unit between the shoulder blades may be more sensitive for detecting accelerations that occur in the upper body (i.e. contact) rather than the lower body (i.e. running).

5.5.6 Conclusions

When the activities performed in RHIE bouts are manipulated, players will set different pacing strategies in order to complete set tasks. When players are required to perform contact efforts, they set a positive pacing strategy where they start with an initially high playing intensity that is reduced in the second game. These reductions in running intensity are greater in the games following contact dominant RHIE bouts. In addition, whilst there are increases in the effective passes from game 1 to game 2 in all conditions other than the 'all contact' condition, there is reduced disposal efficiency observed in the games following the contact dominant bouts. Increases in running loads results in greater lower-body fatigue, whereas greater contact loads leads to increased upper-body fatigue. This study highlights the physical and functional cost of performing contact efforts from both a physical and technical perspective.

5.5.7 Practical Applications

Players should be exposed to a combination of contact and running RHIE bouts to prepare them for the intense demands of rugby league and rugby union competition. These bouts should be tailored to the specific positional demands of the game and reflect the differing contact and running demands between positional groups. Challenging players to maintain performance following RHIE activity may be an effective method of developing their ability to work under pressure and fatigue. Targeting opposition playmakers whilst in attack, making them perform more contact efforts, may lead to greater reductions in their physical and technical performance. Given the demanding nature of RHIE bouts and contact [47, 9] the prescription of any RHIE training should take this into account and be appropriately periodised in order to maximise the adaptive response to training. Future research should aim to determine the efficacy a period of RHIE training has on players' ability to limit the physical and technical reductions observed following RHIE bouts. The fatigue response to rugby league training and competition is likely to be whole-body in nature and this, along with their match activities, should be taken into account when monitoring fatigue and prescribing training in players.

5.5.8 Acknowledgements

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Chapter 6

Conclusions & Applications

6.1 Findings

There are a number of important findings and applications from the studies within this thesis that have relevance to coaching, strength and conditioning and sport science staff.

6.2 Theme 1 – Factors influencing pacing strategies in rugby league players

6.2.1 Conclusions

1. The addition of physical contact to small-sided games, results in players reducing low-speed activity in order to maintain high-intensity activities. Despite this, players are unable to maintain both high-speed running and contact efforts. As such, there is a reduction in high-speed running as players prioritise the maintenance of contact efforts over running efforts.
2. Despite lower running loads during contact small-sided games, players report greater perceived effort than during non-contact games, highlighting that performing physical contact is mentally and physically challenging.
3. Increasing the number of contact efforts from one contact to two and three contacts per bout during small-sided games leads to greater reductions in subsequent playing intensity.
4. Increasing the contact demands of training games weakens the positive relationship between high-intensity running ability and distance covered at moderate- and high-speeds.
5. During intensified competition, players with well-developed physical fitness set an even-paced pacing strategy that can be maintained throughout the tournament. Conversely, players with poorly developed physical qualities set a negative pacing strategy whereby energy is preserved early in the tournament, potentially to minimise increases in post-match fatigue and muscle damage in order to increase playing intensity during the latter stages of the tournament.
6. Players with poorly developed physical fitness, exposed to high-intensity matches can compromise the overall playing intensity of a side during the final games of an intensified competition.

6.2.2 Practical Applications

1. Players need to be exposed to contact and running drills that reflect the most intense periods of match-play on a regular basis during training in an attempt to limit the negative impact of contact on running intensities.
2. Targeting defensive players whilst in possession of the ball, making them perform successive contact efforts with minimal recovery is likely to lead to greater reductions in running intensity which could lead to errors such as dropped balls or missed/ineffective tackles.
3. Although high-intensity running ability is important, focusing solely on this quality is likely to leave players underprepared for the high-intensity contact demands of rugby league match-play. Conditioning programmes should incorporate contact and running drills so that players are prepared for the rigours of competition.
4. Coaching staff should identify players with sub-standard physical fitness early in the pre-season period so that specific conditioning can be carried out in order to develop physical qualities to the required standard.

The results from the first theme of this thesis indicate that both physical contact and fitness influence the pacing strategies players will employ during both match-play and small-sided games. As the contact demands of small-sided games are increased, progressive reductions in relative distance are seen across the course of each game. When the contact demands are relatively low (i.e. single-contact bouts), players tend to reduce the non-essential low-speed activity in an attempt to maintain the high-intensity contact efforts. These findings are in accordance with previous research from Australian rules football and women's soccer where players reduce low-speed or 'non-essential' activity in order to maintain high-speed running efforts [17-19]. However, when the contact demands are increased to multiple efforts in each contact bout, players are unable to maintain all high-intensity activity (i.e. contact and running efforts), perhaps due to increased fatigue [9]. As such, players appear to employ a pacing strategy whereby they attempt to maintain contact efforts, at the cost of high-intensity running. Speculatively, players decide to maintain contact efforts ahead of running activities as they recognise that these are central to success in rugby league [25]. Despite this, maintaining a high relative running intensity is also important to the outcome of a game [55]. Therefore, players need to have the ability to perform the highly demanding contact efforts required during match-play whilst also maintaining a high running intensity. Furthermore, having the capacity to perform the high-intensity running efforts that are commonplace during competition appears critical to minimising fatigue [4].

No previous research has investigated whether the pacing strategies of players are influenced by physical qualities. In the current thesis, the relationship between match activities and physical qualities during small-sided games and intensified competition was explored. During small-sided training games, where the contact demands were manipulated, there were some interesting relationships observed between high-intensity running ability and distances covered during each game. In the single-contact game, when the contact demands were relatively low, there were strong relationships between 30-15 Intermittent Fitness Test (30-15 IFT) performance (a measure of high-intensity running ability) and distance covered at low- ($r = -0.57$), moderate- ($r = 0.57$) and high-speeds ($r = 0.72$). This is in accordance with research from soccer that, like the single contact game, has high relative running loads, but low contact loads [183, 219]. However, as the contact demands were increased from one contact every bout, to two and three contacts per bout, the relationship between 30-15 IFT performance and distances covered during the small-sided games diminished. This suggests that whilst high-intensity running ability is important for running performance when the contact demands are low, as the contact demands are increased, it has less influence on player movements. This supports a growing body of evidence, highlighting, that whilst running fitness is important to running performance, it is not positively associated with the contact and repeated high-intensity effort (RHIE) demands of competition [24, 28]. As such, preparing players for competition by solely using running drills is likely to leave them underprepared for the intense contact and repeated-effort demands of match-play.

During intensified competition, players with well-developed physical fitness competing in high-standard matches, used an even-paced pacing strategy [13]. Conversely, players with poorly developed physical fitness also competing in the high-standard competition showed a positive, or all-out pacing strategy, where their playing intensity was initially high, but reduced as the tournament progressed. A possible explanation for this finding could be that these players initially attempted to maintain a similar intensity set by the high-fitness players, but as the tournament progressed, they reduced playing intensities as a self-preservation mechanism in order to prevent the catastrophic failure of any one physiological system [12, 185]. Alternatively, or in addition to, this pacing strategy set by the low-fitness players, increased fatigue over the competition, could have contributed to reductions in match playing intensities. Low-standard players who possessed lower levels of physical fitness than their high-standard counterparts adopted a pacing strategy that allowed them to preserve energy for the final stages of the competition. They employed a negative pacing strategy, whereby they started with a low playing intensity which gradually increased as the competition progressed [13]. A reason for this negative pacing strategy could be that they were aware that starting the competition with a high playing intensity could result in large increases in fatigue due to poor physical fitness [139]. Therefore, they made a conscious decision to reduce playing intensity and physical collisions, which are a major cause of post-match fatigue [47, 189], in order to minimise increases in fatigue and muscle damage during the early stages of the tournament. It is important to note that in the high-standard group, despite high-fitness players maintaining overall playing intensity across the tournament, there were reductions in team playing intensity due to reductions in the playing intensity of the low-fitness players. Winning sides are able to maintain a greater playing intensity than losing sides [55], as such, any reductions in playing intensity could prove vital to the outcome of a match. With this in mind, it is important that all players meet a minimum level of fitness so individual players do not compromise the overall playing intensity of the team.

Collectively, these data indicate that physical contact is both mentally and physically challenging. Physical fitness appears closely linked to the pacing strategies employed by players. Coaches should ensure that all players meet a minimum level of fitness so team playing intensity is not compromised. Conditioning players solely through running drills is likely to leave them underprepared for the intense contact and repeated-effort demands of competition. With this in mind, coaches should implement training drills that reflect the ‘worst-case’ contact and running sdemands of competition.

6.3 Theme 2 – Post-match fatigue responses in rugby league players: causes and consequences

6.3.1 Conclusions

1. During intensified competition there is insufficient recovery between games, highlighted by progressive increases in markers of fatigue and muscle damage. There are greater increases in blood creatine kinase (CK) and reductions in perceived wellbeing in forwards than backs. This is most likely explained by an increased exposure to physical collisions and RHIE bouts during match-play.
2. Increased markers of muscle damage and fatigue contribute to reductions in match playing intensity. In particular, there are reductions in high-intensity activities, such as RHIE bouts, that can prove vital to the outcome of a game.
3. Increases in blood CK are associated with a reduction in RHIE bouts and an increased time between RHIE bouts, as well as reductions in low-speed activity.
4. The addition of physical contact to small-sided games, results in upper-body neuromuscular fatigue and increased markers of muscle damage compared to non-contact small-sided games.
5. Players with well-developed physical fitness perform greater absolute and relative workloads during match-play than players with poorly developed physical qualities. Despite these increased workloads, high-fitness players exhibit less post-match fatigue and faster recovery times following both single matches and during intensified competition.
6. High-intensity running ability and lower body muscular strength appear central to minimising post-match fatigue and muscle damage.

6.3.2 Practical Applications

1. Given that elevated blood CK is associated with a reduction in high-intensity match activities, it would appear important that players do not begin games with high levels of blood CK.
2. Contact training sessions should be performed well in advance of scheduled or important competitions. Given the reductions in upper-body power following contact

training-games, strength sessions aimed at enhancing muscular power should be performed prior to, or more than 24 hours following contact training sessions.

3. Coaches should identify players with poorly developed aerobic fitness and lower-body muscular strength in order to specifically target and develop these qualities in training to minimise post-match fatigue and recovery time.

Consistent with other findings from intensified tournaments in rugby league [30], basketball [29] and soccer [37], fatigue and muscle damage accumulated over an intensified competition when there was as little as 2 hours between matches. This is unsurprising given the time course taken for full recovery of the neuromuscular system and perceived wellbeing is 24-48 hours following regular rugby league matches [27, 32, 34] and up to 120 hours for markers of muscle damage [35]. These increases in markers of fatigue coincided with reductions in match activities. Indeed, previous work from Australian rules football has highlighted that lower-body neuromuscular fatigue impacts negatively on match performance [38, 39]. In the current thesis, changes in peak power from a countermovement jump (CMJ) only shared small correlations with changes in performance across an intensified competition, whereas increases in CK showed significant and large to very large associations with reductions in low-speed activity, high-speed running, and number and frequency of RHIE bouts. The reason for this disparity could be due to the higher running loads in Australian rules football in comparison to rugby league [41] inducing more lower-body neuromuscular fatigue, and the greater contact loads in rugby league inducing greater levels of muscle damage and upper-body fatigue [47]. CK is somewhat a putative marker of skeletal muscle damage [156, 220] and often shows disconnect to muscle function [27, 189]. Nevertheless, the results of the current research and work of others [40] suggests that elevated CK may lead to reductions in important match activities. As such, players should be free from fatigue and markers of muscle damage prior to competition in order to deliver successful performances.

Increases in markers of muscle damage and reductions in perceived wellbeing were greater in the forwards than the backs over an intensified competition. This is most likely explained by the fact that forwards were involved in a greater absolute number and frequency of physical collisions and RHIE bouts than the backs. Indeed, we observed a large positive correlation between increases in CK and the total number of collisions over the tournament, which is also supported by others [27, 36]. In addition, the increased perceived effort of performing tackles and RHIE bouts may explain the greater reductions in perceived wellbeing [9]. Although these results suggest that collisions and muscle damage are related, correlations do not show cause and effect. However, the finding that increased CK occurs when contact is added to small-sided training games appears to validate these observations. The larger, longer lasting increases in CK following contact small-sided games compared with non-contact games confirms that the blunt force trauma and wrestle efforts associated with collisions and contact during match-play is largely responsible for the changes in CK observed. The smaller increases in CK following the non-contact game clearly highlight that high-speed running efforts, accelerations, and decelerations still induce skeletal muscle damage, but to a lesser extent than when players perform both running efforts and physical contact.

Reductions in upper-body power were also observed alongside the increases in CK following contact small-sided games but not non-contact games. Given the large involvement of the upper-body in the physical collisions that occur during rugby league match-play [11] these findings may be expected, but certainly indicates that simply assessing lower-body fatigue may underestimate the true fatigue response in players participating in contact sports such as rugby league. With this in mind, players should be exposed to collisions in training to prepare mentally and physically for the rigors of competition. These training sessions should occur earlier in the week once recovery from the previous game has occurred, whilst providing players with sufficient time to recover prior to the next scheduled match. Additionally, the upper-body should not be overlooked when monitoring the fatigue status of players or implementing recovery strategies in an attempt to accelerate recovery.

With the intense contact and running demands of competition [2, 62], the observed fatigue responses following match-play are inevitable. Despite this, it is important to determine whether post-match fatigue can be minimised or managed. The findings from the present thesis suggests that players with well-developed physical qualities have greater relative and absolute workloads during competition but experience lower post-match fatigue than their less fit counterparts. This is the case during both single, regular season fixtures and intensified tournaments. Lower-body strength and high-intensity running ability (as measured by the Yo-Yo Intermittent Running Test [IRT], Level 1) are two key qualities that were associated with increased match activities and reduced post-match fatigue. Lower-body strength was associated with increased playing time, distance covered, high-speed running, contact efforts, RHIE bouts and internal load; high-intensity running ability was primarily associated with increases in high- and very-high speed running. These findings are in accordance with previous research [24, 28], clearly demonstrating the importance of physical qualities in rugby league players. Interestingly, well-developed high-intensity running ability did not lead to an increased number of collisions or RHIE bouts during match-play. This supports earlier work from Theme 1 of this thesis [209] as well as the work of others [24, 28] and highlights that specific conditioning needs to be implemented. Once again, simply improving fitness through running drills is likely to leave players underprepared for the intense contact and RHIE demands of competition.

High-intensity running ability appeared to have the greatest influence on post-match fatigue out of all the qualities tested. Players with well-developed high-intensity running ability showed a full recovery of lower-body neuromuscular function by 24 hours whereas players with below average fitness still had a 5% reduction in CMJ power at 48 hours post-match. A similar trend was observed with blood CK, with fitter players experiencing smaller increases in CK than their less fit counterparts, and an almost complete recovery by 48 hours post-match. This recovery of CK by 48 hours in the high-fitness playing group (based on Yo-Yo IRT) is even more remarkable given that previous research, albeit in elite NRL players, has shown that CK may be elevated for up to 120 hours after competition [36]. This certainly highlights the positive impact of well-developed fitness on the fatigue responses observed in players. The differences between players with high and low lower-body strength were less clear although there was a trend for less muscle damage in the players with better-developed lower-body strength. This is of particular note when coupled with the fact that these players performed almost 30% more collisions and 50% more RHIE bouts than their low strength counterparts. As was highlighted earlier in this thesis, contact plays a large role in the muscle damage response [47], so to observe lower CK values in players that performed more contact efforts highlights the protective effect of lower-body strength to post-match rises in CK. A potential explanation for this finding could be that players with better lower-body strength also have better tackling technique [221]. Therefore less effort is required by these players to execute a successful tackle which potentially results in less muscle damage. In addition, increased lower-body strength may allow for greater leg drive when taking the ball into contact resulting in more dominant tackles and smaller increases in CK. With this in mind, in order to minimise post-match fatigue and accelerate recovery, coaching staff should develop physical fitness in players; high-intensity running ability and lower-body strength appear to have the greatest impact on post-match fatigue.

6.4 Summary

In conclusion, the overall aims of this thesis were to determine the impact of various factors on the fatigue response to training and competition and how players paced through matches and small-sided games in order to manage fatigue whilst delivering successful performances. We found that performing contact efforts leads to greater reductions in running intensities during small-sided games compared to non-contact games; these reductions are increased with elevations in the contact demands. Physical contact also leads to increased perceived effort, markers of muscle damage and upper-body neuromuscular fatigue. As such, physical contact is associated with a significant physiological and functional cost.

Well-developed high-intensity running ability leads to increased running loads and intensities performed by players during small-sided games and match-play. However, there is little association between high-intensity running ability and the contact demands of competition. In addition, the relationship between high-intensity running ability and distances covered during small-sided games deteriorates as the contact demands increase. Well-developed physical fitness leads to increased workloads during regular games as well as intensified periods of competition. Despite the increased workloads of fitter players, they suffer less fatigue and muscle damage and recover faster following competition in comparison to their less fit counterparts. Fatigue is an inevitable response to training and competition but this can be minimised through well-developed physical qualities. Players should be regularly exposed to the most intense contact, running, and repeated-effort demands of competition during training so they can develop the specific physical qualities required to maintain match intensities and deliver successful performances.

6.5 Limitations and Future Research

The majority of the limitations in this thesis are discussed within the individual studies presented. One limitation of the overall thesis is that, there were a number of different populations that were used throughout the studies from schoolboy players through to semi-professional players. As such, some of the findings may not be representative of rugby league players on the whole. It would have been advantageous to use the same sample size for each study so that all the findings of each study were applicable to that population, but unfortunately this was not a possibility. In addition to this, all of the studies investigated changes in activity profiles during competitive match-play or small sided games. Whilst these protocols provide us with ecological validity, it is important to note that contextual factors such as match outcome, field position and opposition will influence the observed activity profiles [72, 25, 55]. Based on the findings and limitations discussed in this thesis there are a number of areas that warrant future research. Although it is clear that high-intensity running ability influences pacing strategies employed during competition, the influence of other qualities (such as strength, speed and power) on pacing should be investigated. In addition, only between-game pacing strategies during intensified competition were assessed in the current study. It would be worthwhile investigating how physical qualities influenced pacing strategies within games. Well-developed physical fitness can lead to reductions in post-match fatigue, but it is unknown whether improving fitness over a training period translates to reductions in post-match fatigue. In addition, whilst we showed that some markers of fatigue are associated with reductions in performance, it would be worthwhile to determine the true relationship between fatigue and performance. Investigating whether there are thresholds for certain fatigue markers to determine a players' readiness to train or compete would be particularly important.

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Appendices

Evidence of Publication

Literature Review – Sport Science of Rugby Leauge

Johnston RD, Gabbett TJ, and Jenkins DG. Applied sport science of rugby league. *Sports Med*, 2014, 44: 1087-1100.

From: **Sports Medicine** gabriela.cisneros@springer.com
Subject: Your Submission SPOA-D-13-00230R1
Date: 31 March 2014 13:11
To: Rich Johnston richard.johnston@acu.edu.au

SM

Dear Mr Johnston,

I am writing to inform you that your manuscript, "Applied Sport Science of Rugby League", has been accepted for publication in Sports Medicine. I apologize for the delays in the processing of your manuscript.

Please remember to quote the manuscript number, SPOA-D-13-00230R1, whenever inquiring about your manuscript.

With best regards,

Roger Olney, MBChB
Editor in Chief
Sports Medicine
Adis Journals, Editorial Office

Study 1 – Physical Contact on Pacing

Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on pacing strategies during game-based activities. *Int J Sports Physiol Perform*, 2014, 9: 811-6.

From: ralph.beneke@staff.uni-marburg.de
Subject: International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP_2013_0424.R2
Date: 19 December 2013 01:54
To: richard.johnston@acu.edu.au

18-Dec-2013

Dear Mr. Johnston,

It is a pleasure to accept your manuscript entitled "Influence of physical contact on pacing strategies during game-based activities" in its current form for publication in the International Journal of Sports Physiology and Performance. The comments of the reviewer(s) who reviewed your manuscript are included at the foot of this letter.

The In Press and MedLine listings should be available approximately 4 weeks from now. To facilitate that process, please fill out the attached form transferring copyright to Human Kinetics and send to the journal's Managing Editor, Julia Glahn, at juliag@hkusa.com.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performanc

Study 2 – Three Contact Efforts and Physical Performance

Johnston RD, Gabbett TJ, Walker S, Walker B, and Jenkins DG. Are three contact efforts really reflective of a repeated high-intensity effort bout? *J Strength Cond Res*, 2015, 29: 816-821.

From: **Journal of Strength and Conditioning Research** em@editorialmanager.com
Subject: JSCR Decision ACCEPT
Date: 17 August 2014 23:37
To: Rich Johnston r.johnston88@hotmail.co.uk

JO

CC: jcoburn@fullerton.edu

Aug 17, 2014

RE: JSCR-08-4892R1, entitled "Are three contact efforts really reflective of a repeated high-intensity effort bout?"

Dear Dr. Johnston,

I am pleased to inform you of the official acceptance of your manuscript, JSCR-08-4892R1, entitled "Are three contact efforts really reflective of a repeated high-intensity effort bout?" for publication in the Journal of Strength and Conditioning Research. Congratulations to you and your co-authors in meeting the very high standard of quality that is required for publication in this Journal.

The production staff at Lippincott, Williams and Wilkins (LWW) will be sending galley proofs and work with you to put your manuscript into proper format for publication.

I want to take this opportunity to remind you to check the page proofs promptly and carefully for accuracy when you eventually receive them. You will receive them via email so please be attentive to such communications.

OPEN ACCESS
If you indicated in the revision stage that you would like your submission, if accepted, to be made open access, please go directly to step 2. If you have not yet indicated that you would like your accepted article to be open access, please follow the steps below to complete the process:
1. Notify the journal office via email that you would like this article to be available open access. Please send your Email to jscr@uconn.edu. Please include your article title and manuscript number.
2. A License to Publish (LTP) form must be completed for your submission to be made available open access. Please download the form from http://links.lww.com/LWW-ES/A49, sign it, and Email the completed form to the journal office.
3. **Within 48 hours of receiving this e-mail:** Go to http://wolterskluwer.qconnect.com to pay for open access. You will be asked for the following information. Please enter exactly as shown:
a. Article Title - Are three contact efforts really reflective of a repeated high-intensity effort bout?
b. Manuscript Number - JSCR-08-4892R1

Finally, please be aware that there is usually a delay at this point in time of about 6-9 months before the article will appear in print, due to the high demand for space in the Journal. However, your paper will appear in an "ahead of print" format prior to its formal publication.

We look forward to the submission of other manuscripts from your laboratory. Thank you for your contribution to the JSCR.

We wish you all the best in your future research projects.

Kind Regards,

Jared W Coburn, PhD, CSCS,*D, FNSCA
Senior Associate Editor

Study 3 – Physical Contact on Running

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of the number of contact efforts on running performance during game-based activities. *Int J Sports Physiol Perform*, 2015, 10: 740-745.

From: ralph.beneke@staff.uni-marburg.de
Subject: International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2014-0110.R1
Date: 23 May 2014 04:03
To: richard.johnston@acu.edu.au

22-May-2014

Dear Mr. Johnston,

Manuscript ID IJSPP.2014-0110.R1 entitled "Influence of number of contact efforts on running performance during game-based activities" which you submitted to the International Journal of Sports Physiology and Performance, has been reviewed and rated "ACCEPT with MINOR REVISION". The comments of the reviewer(s) are included at the bottom of this letter.

The reviewer(s) have recommended publication, but also suggest some minor revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

To revise your manuscript, log into http://mc.manuscriptcentral.com/hk_ijspp and enter your Author Center, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.

You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using the track changes mode in MS Word or by using bold or colored text.

Once the revised manuscript is prepared, you can upload it and submit it through your Author Center.

When submitting your revised manuscript, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

IMPORTANT: Your original files are available to you when you upload your revised manuscript. Please delete any redundant files before completing the submission.

Because we are trying to facilitate timely publication of manuscripts submitted to the IJSPP, your revised manuscript should be uploaded as soon as possible. If it is not possible for you to submit your revision in 60 days, we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to the IJSPP and I look forward to receiving your revision.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Study 4 – Pacing During Intensified Competition

Johnston RD, Gabbett TJ, and Jenkins DG. Pacing strategies adopted during a junior team sport tournament depend on playing standard and physical fitness. *Int J Sports Physiol Perform,* 2015, March 10, in press.

From: ralph.beneke@staff.uni-marburg.de
Subject: International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2015-0005.R1
Date: 24 February 2015 22:51
To: richard.johnston@acu.edu.au

24-Feb-2015

Dear Mr. Johnston,

It is a pleasure to accept your manuscript entitled "Pacing strategies adopted during a junior team sport tournament depend on playing standard and physical fitness." in its current form for publication in the International Journal of Sports Physiology and Performance. The comments of the reviewers who reviewed your manuscript are included at the foot of this letter.

The In Press and MedLine listings should be available approximately 4 weeks from now. To facilitate that process, please fill out the attached form transferring copyright to Human Kinetics and send to the journal's Managing Editor, Julia Glahn, at juliag@hkusa.com.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Study 5 – Fatigue and Match Performance

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of an intensified competition on fatigue and match performance in junior rugby league players. *J Sci Med Sport*, 2013, 16: 460-5.

From: **Journal of Science and Medicine in Sport** jsams@elsevier.com
Subject: Your Submission JSAMS-D-12-00368R1 has a received a decision
Date: 19 October 2012 08:17
To: Richard Johnston Richard.Johnston@acu.edu.au

JO

Ms. Ref. No.: JSAMS-D-12-00368R1
Title: Influence of an intensified competition on fatigue and match performance in junior rugby league players
Journal of Science and Medicine in Sport

Dear Mr Rich Johnston,

I am pleased to confirm that your revised paper JSAMS-D-12-00368R1 has now been accepted for publication in Journal of Science and Medicine in Sport.

You may be contacted by the Journal Editorial Office if there is a need to make any minor editorial changes to the manuscript to bring it fully in-line with the Journal style.

Within the next few weeks, you can expect to receive a proof of your paper for final approval. We ask that you give this your prompt attention. About two weeks after the proof has been approved by you, the paper will be published electronically and available for access and download from the Journal website. The print version of your paper will be available as soon as possible after this time, but will depend on our issue publication schedule.

Thank you for submitting your work to this journal.

Yours Sincerely

Gregory Kolt, PhD
Editor-in-Chief
Journal of Science and Medicine in Sport

Study 6 – Contact and Fatigue

Johnston RD, Gabbett TJ, Seibold AJ, and Jenkins DG. Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games. *J Sci Med Sport*, 2014, 17: 535-40.

From: **Journal of Science and Medicine in Sport** jsams@elsevier.com
Subject: Your Submission JSAMS-D-13-00183R2 has a received a decision
Date: 24 July 2013 07:18
To: richard.johnston@acu.edu.au

JO

Ms. Ref. No.: JSAMS-D-13-00183R2
Title: Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games
Journal of Science and Medicine in Sport

Dear Mr. Rich Johnston,

I am pleased to confirm that your revised paper JSAMS-D-13-00183R2 has now been accepted for publication in Journal of Science and Medicine in Sport.

You may be contacted by the Journal Editorial Office if there is a need to make any minor editorial changes to the manuscript to bring it fully in-line with the Journal style.

Within the next few weeks, you can expect to receive a proof of your paper for final approval. We ask that you give this your prompt attention. About two weeks after the proof has been approved by you, the paper will be published electronically and available for access and download from the Journal website. The print version of your paper will be available as soon as possible after this time, but will depend on our issue publication schedule.

Thank you for submitting your work to this journal.

Yours Sincerely

Gregory Kolt, PhD
Editor-in-Chief
Journal of Science and Medicine in Sport

Study 7 – Fitness on Fatigue

Johnston RD, Gabbett TJ, Jenkins DG, and Hulin BT. Influence of physical qualities on post-match fatigue in rugby league players. *J Sci Med Sport*, 2015, 18: 209-213.

From: **Journal of Science and Medicine in Sport** jsams@elsevier.com
Subject: Your Submission JSAMS-D-13-00583R1 has a received a decision
Date: 23 January 2014 14:00
To: richard.johnston@acu.edu.au

Ms. Ref. No.: JSAMS-D-13-00583R1
Title: Influence of physical qualities on post-match fatigue in rugby league players
Journal of Science and Medicine in Sport

Dear Mr. Rich Johnston,

I am pleased to confirm that your revised paper JSAMS-D-13-00583R1 has now been accepted for publication in Journal of Science and Medicine in Sport.

You may be contacted by the Journal Editorial Office if there is a need to make any minor editorial changes to the manuscript to bring it fully in-line with the Journal style.

The accepted, un-edited (and un-typeset) text of your paper will appear in Elsevier's on-line journal database ScienceDirect as an "Article in Press" within only 7 business days. As an "Article in Press" your paper may be cited prior to its publication in an assigned issue of the journal by means of its unique digital object identifier (DOI) number.

Within a few weeks of the accepted version appearing online, you can expect to receive a typeset proof of your paper for final approval. We ask that you give this your prompt attention. About two weeks after the proof has been approved by you, the final version of your paper will be published electronically as an "Article in Press" and will replace the earlier un-edited version. This article will be available for access and download from the Journal website and may be cited by means of its DOI. The print version of your paper will be available as soon as possible after this time, but will depend on our issue publication schedule.

Thank you for submitting your work to this journal.

Yours Sincerely

Gregory Kolt, PhD
Editor-in-Chief
Journal of Science and Medicine in Sport

Study 8 – Playing Standard, Fitness and Fatigue

Johnston RD, Gabbett TJ, and Jenkins DG. Influence of playing standard and physical fitness on activity profiles and post-match fatigue during intensified rugby league competition. *Sports Med Open*, 2015, March 22.

From: **SpringerOpen Production Team** SpringerOpen_Production@spi-global.com
Subject: Final PDF proof: Sports Medicine - Open, 40798_2015_15
Date: 28 March 2015 00:55
To: Rich D Johnston richard.johnston@acu.edu.au

SP

Author list: Rich D Johnston, Tim J Gabbett, David G Jenkins
Title: Influence of playing standard and physical fitness on activity profiles and post-match fatigue during intensified junior rugby league competition
Journal: Sports Medicine – Open
MS ID: SMOA-D-15-00016.0
JWF MS ID: 40798_2015_15

Dear Rich D Johnston,

We are pleased to inform you that a final PDF proof of your article is now available for you to check. The PDF can be found at the following link:

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Thank you very much.

With respect and warm regards,

SpringerOpen Production Team

Study 9 – Repeated Efforts and Subsequent Performance

Johnston RD, Gabbett TJ, Jenkins DG, and Speranza, MJ. The effect of different repeated high-intensity effort bouts on subsequent running, skill performance and neuromuscular function. *Int J Sports Physiol Perform, in press*, 2015.

ralph.beneke@staff.uni-marburg.de

To: Rich ACU

International Journal of Sports Physiology and Performance - Decision on Manuscript ID IJSPP.2015-0243.R2

16 July 2015 18:53

Inbox - Work

R

16-Jul-2015

Dear Mr. Johnston,

It is a pleasure to accept your manuscript entitled "The effect of different repeated high-intensity effort bouts on subsequent running, skill performance and neuromuscular function" in its current form for publication in the International Journal of Sports Physiology and Performance.

The In Press and MedLine listings should be available approximately 4 weeks from now. To facilitate that process, please fill out the attached form transferring copyright to Human Kinetics and send to the journal's Managing Editor, Julia Glahn, at juliag@hkusa.com. If you already uploaded the form upon submission, please disregard.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sports Physiology and Performance, we look forward to your continued contributions to the Journal.

Yours sincerely,

Prof. Ralph Beneke MD PhD FACSM
Editor, International Journal of Sports Physiology and Performance

Information Letters and Consent Forms

Study 1 – Physical Contact on Pacing

Information Letter

PROJECT TITLE: Influence of contact on fatigue and pacing in small-sided games

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett
STUDENT RESEARCHER: Richard Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the influence of contact on running performance and fatigue during and following small-sided games. The information from this study will identify whether performing more contact efforts in a single bout results in greater reductions in running performance, and whether this can be improved through training. You have been approached to participate in this study because you are a junior elite rugby league player competing in the top league in Australia.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carried out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. mouthguard) must be worn during the contact component of the games. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. There is a qualified physiotherapist on hand should you sustain an injury during the study. The push-up and jump will be conducted following a warm-up and are performed on a purpose built platform that will be positioned free from any objects or obstacles. The fingertip blood sample involves a small pin prick and the collection of a few drops of blood and offers minimal discomfort. The pin prick is administered using sterilised, one-use lancets. Prior to the blood sample, the finger is cleaned and the experimenter will wear disposable gloves. All consumables will be discarded into a sharps bin. All these steps are taken to minimise the risk of infection

What will I be asked to do?

As a participant in this study, you will be asked to:

- You will be asked to perform 2 small-sided games, one with contact, one without. Each game will last for 16 minutes. Immediately prior to the protocol, you will be asked to perform one countermovement jump on a force platform to measure neuromuscular fatigue, provide a small blood sample by way of a pin prick to the fingertip, and complete a short questionnaire. These measures will then be repeated immediately after the protocol and at 12, 36 and 48hr after the games. It is expected that these measures will take no more than 10 minutes of your time on each testing occasion. The 2 small-sided games will be separated by 72 hours and will form part of your training for the week.
- The questionnaire will ask you to rate fatigue, muscle soreness, mood, stress, and sleep quality on 0-5 scales.
- During the small-sided games, you will be asked to wear GPS devices to track movements and activities over the course of the game.
- All of the testing will occur at the club's training ground.

How much time will the project take?

- There will be no extra time commitments on top of your current training times.

What are the benefits of the research project?

The information will highlight the influence physical contact has on your fatigue following and performance during small-sided games. It will provide coaching staff with important information that will inform training.

Can I withdraw from the study?

Yes, you are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au

Student Researcher:
Rich Johnston
07 3623 7726
richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University. If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
North Sydney, NSW 2059

Ph: 03 9953 3150

Fax: 03 9953 3315

Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett — Principal Investigator

Rich Johnston — Student Investigator

Consent Form

TITLE OF PROJECT: Influence of contact on fatigue and pacing in small-sided games

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves performing 2 small-sided training games, wearing a GPS unit, and performing a jump and push-up and a fingertip blood sample following each game.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE...................................

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: .... DATE ……………....................

Study 2 – Three Contact Efforts and Physical Performance

Information Letter

PROJECT TITLE: Are three contact efforts really reflective of a repeated-effort bout?

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Richard Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the influence of contact on running performance during small-sided games. The information from this study will identify whether performing more contact efforts in a single bout results in greater reductions in running performance, and whether this can be improved through training. You have been approached to participate in this study because you are a rugby league player competing in the top league in Queensland.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carried out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. mouthguard) must be worn during the contact component of the games. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. There is a qualified physiotherapist on hand should you sustain an injury during the study.

What will I be asked to do?

As a participant in this study, you will be asked to:

- Complete 3 different fitness tests, the yo-yo intermittent recovery test, and 1RM in the bench press and squat. This fitness testing battery will take approximately 40 minutes to complete, and will be performed during regular training.
- Seven days later, you will be asked to perform the first small-sided game which lasts 24 minutes. You will then perform the second game 2 days later, and the third 4 days later. Each game consists of running and wrestling bouts. In each wrestling bout you will be asked to perform 1, 2, or 3 contact efforts. You will wear GPS units during each game to record information on movements and speeds.
- You will then perform 6 weeks of structured training before performing the physical quality tests again and one small-sided game.

How much time will the project take?

- There will be no extra time commitments on top of your current training times.

What are the benefits of the research project?

The information will highlight your strengths and weaknesses and how this relates to small-sided game performance. It will provide coaching staff with important information that will inform match tactics.

Can I withdraw from the study?

Yes, you are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au

Student Researcher:
Rich Johnston
07 3623 7726
richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University. If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
North Sydney, NSW 2059
Ph: 03 9953 3150
Fax: 03 9953 3315
Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: Are three contact efforts really reflective of a repeated-effort bout?

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves performing 3 small-sided training games, wearing a GPS unit, and carrying out 6 weeks of training prescribed by the club's coaches.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE...................................

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: .... DATE: ……………….........

Study 3 – Physical Contact on Running

Information Letter

PROJECT TITLE: Influence of the number of contact efforts on subsequent running performance during game-based training activities

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett
STUDENT RESEARCHER: Richard Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the influence of contact on running performance during small-sided games. The information from this study will identify whether performing more contact efforts in a single bout results in greater reductions in running performance, and whether this can be improved through training. You have been approached to participate in this study because you are a rugby league player competing in the top league in Queensland.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carried out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. mouthguard) must be worn during the contact component of the games. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. There is a qualified physiotherapist on hand should you sustain an injury during the study.

What will I be asked to do?

As a participant in this study, you will be asked to:

- Complete 3 different fitness tests, the yo-yo intermittent recovery test, and 1RM in the bench press and squat. This fitness testing battery will take approximately 40 minutes to complete, and will be performed during regular training.
- Seven days later, you will be asked to perform the first small-sided game which lasts 24 minutes. You will then perform the second game 2 days later, and the third 4 days later. Each game consists of running and wrestling bouts. In each wrestling bout you will be asked to perform 1, 2, or 3 contact efforts. You will wear GPS units during each game to record information on movements and speeds.
- You will then perform 6 weeks of structured training before performing the physical quality tests again and one small-sided game.

How much time will the project take?

- There will be no extra time commitments on top of your current training times.

What are the benefits of the research project?

The information will highlight your strengths and weaknesses and how this relates to small-sided game performance. It will provide coaching staff with important information that will inform match tactics.

Can I withdraw from the study?

Yes, you are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au

Student Researcher:
Rich Johnston
07 3623 7726
richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University. If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University, North Sydney Campus
PO Box 968
North Sydney, NSW 2059
Ph: 03 9953 3150
Fax: 03 9953 3315
Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: Influence of the number of contact efforts on subsequent running performance during game-based training activities

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves performing 3 small-sided training games, wearing a GPS unit, and carrying out 6 weeks of training prescribed by the club's coaches.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: ....   DATE...................................

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: ....   DATE: ……………….........

Study 4 – Pacing During Intensified Competition

Information Letter

PROJECT TITLE: The influence of playing standard on fatigue and match performance during an intensified rugby league competition

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the fatigue responses to an intensified period of junior rugby league competition. The knowledge gained from this study will help coaches and game administrators plan training and competition schedules more effectively in order to reduce excessive fatigue. In addition, this study is the first to investigate the relationships between playing level, fatigue, and match performance. You have been approached to participate in this study because you are competing in the Confraternity rugby league carnival in 2014.

Who is undertaking the project?

This project is being conducted by Dr. Tim Gabbett and Rich Johnston and will form the basis for the degree of PhD at Australian Catholic University under the supervision of Dr. Tim Gabbett.

What will I be asked to do?

- Compete in rugby league games during the 2014 Confraternity Carnival held at Aqiunas College.
- Prior to the tournament perform the Yo-Yo intermittent recovery test to measure fitness. The test will be done during a team training session at your school, and will take approximately 15 minutes. The test is similar to the beep test and requires you to perform 20 m shuttles at increasing speeds until you cannot keep in time with the audio signals.

- Wear a GPS unit during each game of the tournament in order to track player speeds and movements.
- Before and after each game of the tournament, fatigue measures will be taken to track changes in fatigue.
    - Perform a jump and a push-up on a force platform to measure upper- and lower-body power (2 min).
    - Provide a fingertip blood sample to measure muscle damage (2 min).
    - Complete a short questionnaire to rate feelings of fatigue, soreness, mood, stress and sleep quality (1 min).

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible and aside from a small fingertip blood sample before and after each game will not be beyond those you experience during your normal training and competition. In case of any unlikely circumstance (e.g. chronic conditions, injury), medical staff will be on hand to manage the situation.

The GPS units worn during the matches are regularly worn by players in the NRL and have been approved for competition use by the Australian rugby league. The units have been specifically designed to be worn in a place (top of back, between shoulder blades) that is unlikely to come into contact with the ground or another player. Furthermore, the units are small (approximately the size of a small mobile phone) and worn in a padded compartment of a custom designed vest as to minimise any risk to the player if they do happen to land on the unit.

The countermovement jump and push-up players are required to perform offer very little risk. The platform will be placed on a stable surface and clear of any objects that may injure players if they were to lose balance. Prior to performing the exercises, players will undergo a standardised warm-up to minimise the risk of muscle strains. Furthermore, the players will only perform 1 jump and 1 push-up at any one time, further minimising the risk of injury.

Whilst a blood sample may sound extreme, the routine requires only a finger prick and a small sample of blood (4-5 drops). As blood is being collected all appropriate measures will be taken to minimise the risk of contamination and infection. The experimenter will be wearing rubber gloves, and will clean the finger with an alcohol swab prior to pricking the skin. The skin will be pricked using sterilised equipment. Pressure will be applied to the finger with a tissue after collection of each blood sample. All materials used in the blood sample collection process are placed into either a sharps bin or a biohazard bin before being incinerated. The experimenter has over 5 years' experience collecting blood samples, which will minimise discomfort to the participant. It is important to note that no foreign bodies will be injected into players during the collection of the blood sample or any procedure associated with this study.

As the Yo-Yo intermittent recovery test requires maximal exertion, players with any health concerns or injuries will not be required to perform the test. Prior to the test, players will perform a thorough warm-up in order to minimise the risk of sustaining an injury.

How much time will the project take?

Other than competing in the games during the competition, little time will be taken up by fitting the GPS units to each player prior to each game (1 min/player); performing a jump and push-up before and after each game (2 min/player); filling out the questionnaire (1min/player) each day; providing a fingertip blood sample each day (2 min/player). In total, players will need to give up approximately 15 min of their time each day of the tournament.

What are the benefits of the research project?

The findings of this research will help your coaches improve your training and preparation for subsequent tournaments by adjusting training activities to help you with post-match recovery. The results will potentially allow game administrators to alter competition schedules to help reduce the likelihood of player overtraining and burnout as well as other negative training adaptations. It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this study. Please note that you will not be named within this report and no one other than the team of researchers will be able to identify your results at any time during or following the testing. An identification number will be assigned to your data, known only to the researchers.

Can I withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

The researchers aim to present the information collected in a publication. In no way will your results be identifiable, only group averages will be reported.

Will I be able to find out the results of the project?

Yes, each participant will be emailed a copy of their individual results on completion of the study.

Who do I contact if I have questions about the project?

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au
School of Exercise Science
ACU National, McAuley Campus, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2013 xxxx). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Research Ethics Manager
Office of the Deputy Vice-Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
North Sydney
NSW 2059
Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

You should sign both copies of the consent form. Please retain one copy for your records and return the other copy to the Principal Investigator.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: The influence of playing standard on fatigue and match performance during an intensified rugby league competition

NAME OF PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

NAME OF STUDENT RESEARCHER: Rich Johnston

I .... (*the parent/guardian*) have read (*or, where appropriate*, have had read to me) and understood the information provided in the Information Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may perform the Yo-Yo intermittent recovery test; a jump on a force platform to asses muscle fatigue; provide a small fingertip blood sample to measure muscle damage; and fill out a questionnaire to determine perceptions of wellbeing before and after each game. In addition, they may wear a GPS unit during each match to assess playing intensity. I realise that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE ....……………………… Date: ....

NAME OF CHILD ....

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:................................

SIGNATURE OF STUDENT RESEARCHER:..Date:................................

ASSENT OF PARTICIPANTS AGED UNDER 18 YEARS

I ……………………… (*the participant aged under 18 years*) understand what this research project is designed to explore the impact of fatigue on match performance in rugby league competition. What I will be asked to do has been explained to me. I agree to take part in the study realising that I can withdraw at any time without having to give a reason for my decision.

NAME OF PARTICIPANT AGED UNDER 18: ....

SIGNATURE: ....Date:................................

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:................................

Study 5 – Fatigue and Match Performance

Information Letter

TITLE OF PROJECT: Physiological responses to an intensified period of junior rugby league competition

PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

Dear Participant,

You are invited to participate in a study investigating the responses to an intensified period of junior rugby league competition. The knowledge gained from this study will help coaches and game administrators plan training and competition schedules more effectively in order to reduce excessive fatigue. In addition, this study is the first to investigate the relationships between fatigue an match performance. You have been approached to participate in this study because you are competing in the Confraternity rugby league carnival in Shorncliffe.

The possible risks, inconvenience and/or discomfort to you are negligible and aside from a small blood sample before and after each game will not be beyond those you experience during your normal training and competition. In case of any unlikely circumstance (e.g. chronic conditions, injury), medical staff will be on hand to manage the situation.

You will be asked to wear a small GPS unit during each match at the Confraternity carnival. GPS units are widely used in the NRL and Queensland Cup; they provide information on player movements (e.g. distance covered, tackles etc.) throughout the match. In addition to GPS, each game will be recorded by a video camera to gather match statistics (e.g. number of tackles, tries). Your time commitments aside from competing in each game will be minimal. Before each game you will be asked to fill out a questionnaire ranking fatigue, muscle soreness, mood, sleep quality and stress on a scale from 1-5 with 0.5 increments (approximately 2min); perform a jump on a force platform (approximately 2min) to determine muscle fatigue; and provide a small blood sample following a pin prick to the finger tip (approximately 2min) in order to determine muscle damage. In addition to this, you will be required to perform the jump and provide a blood sample after each game of the competition.

Each blood sample is collected via a pin prick to the finger, and the amount of blood taken is equivalent to a small drop of blood, this blood sample will determine the amount muscle damage induced by a junior rugby league game. As such, the discomfort and risks posed by these procedures are minimal. These measures have never been conducted in junior players, so your participation in the study will be greatly appreciated.

The findings of this research will help your coaches improve your training and preparation for subsequent tournaments by adjusting training activities to help you with post-match recovery. The results will potentially allow game administrators to alter competition schedules to help reduce the likelihood of player overtraining and burnout as well as other negative training adaptations. It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this study. Please note that you will not be named within this report and no one other than the team of researchers will be able to identify your results at any time during or following the testing. An identification number will be assigned to your data, known to only the researchers.

Be advised that as a participant and or parent/guardian you are free to refuse consent altogether without having to justify that decision, and if you wish to, can withdraw consent and discontinue participation in the study at any time without giving a reason. Withdrawal from the research study will not impact upon your team selection.

Should you have any questions regarding this project, please use the following contacts

Principal Investigator:	Student Researcher:
Dr. Tim Gabbett	Rich Johnston
07 3623 7589	07 3623 7726
tim.gabbett@acu.edu.au	richard.johnston@acu.edu.au

School of Exercise Science

ACU National, McAuley Campus, 1100 Nudgee Road, Banyo, QLD, 4014

On completion of the study, we would be delighted to discuss with you the findings of the study, and your individual results.

Before deciding to take part in this study, it is important for you to be aware that this study has gained approval by the Human Research Ethics Committee at Australian Catholic University. This vigorous process ensures that the study is worthwhile and protects you the participant.

In the event that you have any complaint or concern about the way you have been treated during the study, or if you have any query that the Investigators have not been able to satisfy, you may write to the Chair of the Human Research Ethics Committee care of the Victorian Research Services Unit.

Chair, HREC
C/o Research Services
Australian Catholic University
Melbourne Campus
Locked Bag 4115
FITZROY VIC 3065
Tel: 03 9953 3158 Fax: 03 9953 3315

Any complaint or concern will be treated in confidence and fully investigated. The participant will be informed of the outcome.

If you agree to participate in this project, you should sign both copies of the Consent Form. Please retain one copy for your records and return the other copy to the Principal Investigator.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: Physiological responses to an intensified period of junior rugby league competition

NAME OF PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

NAME OF STUDENT RESEARCHER: Rich Johnston

I .... (*the parent/guardian*) have read (*or, where appropriate*, have had read to me) and understood the information provided in the Information Letter to the Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may, perform a jump on a force platform to asses muscle fatigue; provide a small blood sample to measure muscle damage; and fill out a questionnaire to determine perceptions of wellbeing before and after each game. In addition, they may wear a GPS unit during each match, as well as having each game video recorded to measure match intensity and performance. I realise that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE ....……………………… Date: ....

NAME OF CHILD ....

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:................................

SIGNATURE OF STUDENT RESEARCHER: ....Date:................................

ASSENT OF PARTICIPANTS AGED UNDER 18 YEARS

I ……………………… (*the participant aged under 18 years*) understand what this research project is designed to explore the impact of fatigue on match performance in rugby league competition. What I will be asked to do has been explained to me. I agree to take part in the study realising that I can withdraw at any time without having to give a reason for my decision.

NAME OF PARTICIPANT AGED UNDER 18: ....

SIGNATURE: ....Date:..................................

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:..................................

SIGNATURE OF STUDENT RESEARCHER:[if applicable] ....Date:..................................

Study 6 – Conact and Fatigue

Information Letter

PROJECT TITLE: Influence of contact on fatigue and pacing in small-sided games

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett
STUDENT RESEARCHER: Richard Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the influence of contact on running performance and fatigue during and following small-sided games. The information from this study will identify whether performing more contact efforts in a single bout results in greater reductions in running performance, and whether this can be improved through training. You have been approached to participate in this study because you are a junior elite rugby league player competing in the top league in Australia.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carried out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. mouthguard) must be worn during the contact component of the games. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. There is a qualified physiotherapist on hand should you sustain an injury during the study. The push-up and jump will be conducted following a warm-up and are performed on a purpose built platform that will be positioned free from any objects or obstacles. The fingertip blood sample involves a small pin prick and the collection of a few drops of blood and offers minimal discomfort. The pin prick is administered using sterilised, one-use lancets. Prior to the blood sample, the finger is cleaned and the experimenter will wear disposable gloves. All consumables will be discarded into a sharps bin. All these steps are taken to minimise the risk of infection

What will I be asked to do?

As a participant in this study, you will be asked to:

- You will be asked to perform 2 small-sided games, one with contact, one without. Each game will last for 16 minutes. Immediately prior to the protocol, you will be asked to perform one countermovement jump on a force platform to measure neuromuscular fatigue, provide a small blood sample by way of a pin prick to the fingertip, and complete a short questionnaire. These measures will then be repeated immediately after the protocol and at 12, 36 and 48hr after the games. It is expected that these measures will take no more than 10 minutes of your time on each testing occasion. The 2 small-sided games will be separated by 72 hours and will form part of your training for the week.
- The questionnaire will ask you to rate fatigue, muscle soreness, mood, stress, and sleep quality on 0-5 scales.
- During the small-sided games, you will be asked to wear GPS devices to track movements and activities over the course of the game.
- All of the testing will occur at the club's training ground.

How much time will the project take?

- There will be no extra time commitments on top of your current training times.

What are the benefits of the research project?

The information will highlight the influence physical contact has on your fatigue following and performance during small-sided games. It will provide coaching staff with important information that will inform training.

Can I withdraw from the study?

Yes, you are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au

Student Researcher:
Rich Johnston
07 3623 7726
richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University. If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
North Sydney, NSW 2059
Ph: 03 9953 3150
Fax: 03 9953 3315

Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: Influence of contact on fatigue and pacing in small-sided games

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves performing 2 small-sided training games, wearing a GPS unit, and performing a jump and push-up and a fingertip blood sample following each game.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE...................................

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: .... DATE ……….....................

Study 7 – Fitness on Fatigue

Information Letter

PROJECT TITLE: The influence of fitness on the fatigue response to rugby league competition.

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Richard Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the influence of fitness on the fatigue response to a simulated rugby league game. The information from this study will identify key fitness qualities that influence the fatigue response following competition. You have been approached to participate in this study because you are a rugby league player competing in the top league in Queensland.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carries out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. gum shield) must be worn during the contact component of the simulated game. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. The countermovement jump will be performed on a force platform with a rubber surface in trainers to maximise grip, in addition, the area around the platform will be clear of any obstructions that could cause harm in the case of a fall. The blood sample required at each testing occasion will be performed with sterilised equipment in order to prevent infection. Furthermore, the blood sample will be collected by a suitably qualified and experienced individual in order to minimise any discomfort it may cause. The blood sample itself is taken by a small prick to the finger and a small amount of blood is collected, as such, the pain from this process is minimal.

What will I be asked to do?

As a participant in this study, you will be asked to:

- Complete 4 different fitness tests, the yo-yo intermittent recovery test, a 1.2 km time trial, a countermovement jump on a force platform, and a 3RM in the bench press and squat this fitness testing battery will take approximately 90 minutes to complete, and will be performed during regular training.
- Seven days later, you will be asked to play a rugby league game. Immediately prior to the protocol, you will be asked to perform one countermovement jump on a force platform to measure neuromuscular fatigue, provide a small blood sample by way of a pin prick to the fingertip, and complete a short questionnaire. These measures will then be repeated immediately after the protocol and at 24, and 48 hrs after the game. It is expected that these measures will take no more than 10 minutes of your time on each testing occasion. The simulated game will be a full contact game played amongst members of the squad during training.
- The questionnaire will ask you to rate fatigue, muscle soreness, mood, stress, and sleep quality on 0-5 scales.
- During the game, you will be asked to wear GPS devices to track movements and activities over the course of the game.
- All of the testing will occur at the club's training ground.

How much time will the project take?

- The fitness tests will take approximately 90 minutes
- The game will take 80 minutes
- The measures of fatigue will take approximately 10 minutes on each of the 3 occasions, totaling 30 minutes.
- The measurement of fatigue is the only time commitment that will occur on top of your training commitments. As such, your time commitments to participate in this study are minimal.

What are the benefits of the research project?

The information from this study will allow coaching staff to develop specific conditioning practices to help reduce post-competition fatigue, and optimise your preparation for the next game.

Can I withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable to you.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:	**Student Researcher:**
Dr. Tim Gabbett	Rich Johnston
07 3623 7589	07 3623 7726
tim.gabbett@acu.edu.au	richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2012 xxxx). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Chair, HREC
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
Melbourne Campus
Locked Bag 4115
FITZROY, VIC, 3065
Ph: 03 9953 3150
Fax: 03 9953 3315
Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: The influence of playing standard on fatigue and match performance during an intensified rugby league competition

NAME OF PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

NAME OF STUDENT RESEARCHER: Rich Johnston

I .... (*the parent/guardian*) have read (*or, where appropriate*, have had read to me) and understood the information provided in the Information Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that I will be asked to perform the Yo-Yo intermittent recovery test; a jump on a force platform to asses muscle fatigue; provide a small fingertip blood sample to measure muscle damage; and fill out a questionnaire to determine perceptions of wellbeing before and after each game. In addition, they may wear a GPS unit during a game to assess playing intensity. I realise that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARTICIPANT: ....

SIGNATURE: .... DATE...................................

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: .... DATE ……….....................

Study 8 – Playing Standard, Fitness and Fatigue

Information Letter

PROJECT TITLE: The influence of playing standard on fatigue and match performance during an intensified rugby league competition

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The research project investigates the fatigue responses to an intensified period of junior rugby league competition. The knowledge gained from this study will help coaches and game administrators plan training and competition schedules more effectively in order to reduce excessive fatigue. In addition, this study is the first to investigate the relationships between playing level, fatigue, and match performance. You have been approached to participate in this study because you are competing in the Confraternity rugby league carnival in 2014.

Who is undertaking the project?

This project is being conducted by Dr. Tim Gabbett and Rich Johnston and will form the basis for the degree of PhD at Australian Catholic University under the supervision of Dr. Tim Gabbett.

What will I be asked to do?

- Compete in rugby league games during the 2014 Confraternity Carnival held at Aqiunas College.
- Prior to the tournament perform the Yo-Yo intermittent recovery test to measure fitness. The test will be done during a team training session at your school, and will take approximately 15 minutes. The test is similar to the beep test and requires you to perform 20 m shuttles at increasing speeds until you cannot keep in time with the audio signals.

- Wear a GPS unit during each game of the tournament in order to track player speeds and movements.
- Before and after each game of the tournament, fatigue measures will be taken to track changes in fatigue.
    - Perform a jump and a push-up on a force platform to measure upper- and lower-body power (2 min).
    - Provide a fingertip blood sample to measure muscle damage (2 min).
    - Complete a short questionnaire to rate feelings of fatigue, soreness, mood, stress and sleep quality (1 min).

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible and aside from a small fingertip blood sample before and after each game will not be beyond those you experience during your normal training and competition. In case of any unlikely circumstance (e.g. chronic conditions, injury), medical staff will be on hand to manage the situation.

The GPS units worn during the matches are regularly worn by players in the NRL and have been approved for competition use by the Australian rugby league. The units have been specifically designed to be worn in a place (top of back, between shoulder blades) that is unlikely to come into contact with the ground or another player. Furthermore, the units are small (approximately the size of a small mobile phone) and worn in a padded compartment of a custom designed vest as to minimise any risk to the player if they do happen to land on the unit.

The countermovement jump and push-up players are required to perform offer very little risk. The platform will be placed on a stable surface and clear of any objects that may injure players if they were to lose balance. Prior to performing the exercises, players will undergo a standardised warm-up to minimise the risk of muscle strains. Furthermore, the players will only perform 1 jump and 1 push-up at any one time, further minimising the risk of injury.

Whilst a blood sample may sound extreme, the routine requires only a finger prick and a small sample of blood (4-5 drops). As blood is being collected all appropriate measures will be taken to minimise the risk of contamination and infection. The experimenter will be wearing rubber gloves, and will clean the finger with an alcohol swab prior to pricking the skin. The skin will be pricked using sterilised equipment. Pressure will be applied to the finger with a tissue after collection of each blood sample. All materials used in the blood sample collection process are placed into either a sharps bin or a biohazard bin before being incinerated. The experimenter has over 5 years' experience collecting blood samples, which will minimise discomfort to the participant. It is important to note that no foreign bodies will be injected into players during the collection of the blood sample or any procedure associated with this study.

As the Yo-Yo intermittent recovery test requires maximal exertion, players with any health concerns or injuries will not be required to perform the test. Prior to the test, players will perform a thorough warm-up in order to minimise the risk of sustaining an injury.

How much time will the project take?

Other than competing in the games during the competition, little time will be taken up by fitting the GPS units to each player prior to each game (1 min/player); performing a jump and push-up before and after each game (2 min/player); filling out the questionnaire (1min/player) each day; providing a fingertip blood sample each day (2 min/player). In total, players will need to give up approximately 15 min of their time each day of the tournament.

What are the benefits of the research project?

The findings of this research will help your coaches improve your training and preparation for subsequent tournaments by adjusting training activities to help you with post-match recovery. The results will potentially allow game administrators to alter competition schedules to help reduce the likelihood of player overtraining and burnout as well as other negative training adaptations. It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this study. Please note that you will not be named within this report and no one other than the team of researchers will be able to identify your results at any time during or following the testing. An identification number will be assigned to your data, known only to the researchers.

Can I withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences.

Will anyone else know the results of the project?

The researchers aim to present the information collected in a publication. In no way will your results be identifiable, only group averages will be reported.

Will I be able to find out the results of the project?

Yes, each participant will be emailed a copy of their individual results on completion of the study.

Who do I contact if I have questions about the project?

Principal Investigator:

Dr. Tim Gabbett

07 3623 7589

tim.gabbett@acu.edu.au

School of Exercise Science

ACU National, McAuley Campus, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2013 xxxx). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Research Ethics Manager

Office of the Deputy Vice-Chancellor (Research)

Australian Catholic University

North Sydney Campus

PO Box 968

North Sydney

NSW 2059

Email: res.ethics@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?

You should sign both copies of the consent form. Please retain one copy for your records and return the other copy to the Principal Investigator.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: The influence of playing standard on fatigue and match performance during an intensified rugby league competition

NAME OF PRINCIPAL SUPERVISOR: Dr. Tim Gabbett

NAME OF STUDENT RESEARCHER: Rich Johnston

I .... (*the parent/guardian*) have read (*or, where appropriate*, have had read to me) and understood the information provided in the Information Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may perform the Yo-Yo intermittent recovery test; a jump on a force platform to asses muscle fatigue; provide a small fingertip blood sample to measure muscle damage; and fill out a questionnaire to determine perceptions of wellbeing before and after each game. In addition, they may wear a GPS unit during each match to assess playing intensity. I realise that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....

SIGNATURE ....……………………… Date: ....

NAME OF CHILD ....

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:................................

SIGNATURE OF STUDENT RESEARCHER:...Date:................................

ASSENT OF PARTICIPANTS AGED UNDER 18 YEARS

I ……………………… (*the participant aged under 18 years*) understand what this research project is designed to explore the impact of fatigue on match performance in rugby league competition. What I will be asked to do has been explained to me. I agree to take part in the study realising that I can withdraw at any time without having to give a reason for my decision.

NAME OF PARTICIPANT AGED UNDER 18: ....

SIGNATURE: ....Date:.................................

SIGNATURE OF PRINCIPAL SUPERVISOR: ....Date:.................................

Study 9 – Repeated Efforts and Performance

Information Letter

PROJECT TITLE: The influence of training on fitness and the fatigue response to simulated rugby league competition

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett
STUDENT RESEARCHER: Richard Johnston
STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

The aim of this research is to determine whether any changes in fitness influence the fatigue response to rugby league small sided games.You have been approached to participate in this study because you are a rugby league player competing in the top league in Queensland.

Who is undertaking the project?

This project is being conducted by Rich Johnston and will form the basis for the degree of his PhD at Australian Catholic University under the supervision of Dr. Tim Gabbett.

Are there any risks associated with participating in this project?

The possible risks, inconvenience and/or discomfort to you are negligible. Extensive warm-ups will be carried out before any physical activity is performed to reduce the risk of injury. Protective equipment (e.g. gum shield) must be worn during the simulated game. The GPS devices worn during training and the simulated game are worn in a specifically designed vest, with the unit located on the upper back in a padded compartment in order to minimise the risk of falling on the unit. The countermovement jump will be performed on a force platform with a rubber surface in trainers to maximise grip, in addition, the area around the platform will be clear of any obstructions that could cause harm in the case of a fall. You will undertake a period of 6 weeks of pre-season training that will be prescribed by the club's coaching staff.

What will I be asked to do?

As a participant in this study, you will be asked to:

- Complete 4 different fitness tests, the yo-yo intermittent recovery test, a 1.2 km time trial, a countermovement jump on a force platform, and a 3RM in the bench press and squat this fitness testing battery will take approximately 90 minutes to complete, and will be performed during regular training.
- Three days later, you will be asked to perform a simulated rugby league game, which lasts for approximately 80 minutes. Immediately prior to the protocol, you will be asked to perform one countermovement jump on a force platform to measure neuromuscular fatigue and complete a short questionnaire. These measures will then be repeated immediately after the protocol and at 24 and 48 hours after the game. It is expected that these measures will take no more than 5 minutes of your time on each testing occasion. The simulated game will be a full contact game played amongst members of the squad during training.
- The questionnaire will ask you to rate fatigue, muscle soreness, mood, stress, and sleep quality on 0-5 scales.
- During the simulated game, you will be asked to wear GPS devices to track movements and activities over the course of the game. The games will also be recorded by a video camera to assess skill involvements like the rest of your skills sessions are.
- All of the testing will occur at the club's training ground.
- You will perform these fitness tests, simulated game and fatigue tests at the start and end of a 6 week pre-season training period

How much time will the project take?

- The fitness tests will take approximately 90 minutes
- The simulated game will take 40 minutes
- The measures of fatigue will take approximately 5 minutes on each of the 4 occasions, totalling 20 minutes.
- The measurement of fatigue is the only time commitment that will occur on top of your training commitments. As such, your time commitments to participate in this study are minimal.

What are the benefits of the research project?

The information from this study will allow coaching staff to develop specific conditioning practices to help reduce post-competition fatigue, and optimise your preparation for the next game. You will also engage in a training period aimed at improving your physical performance

Can I withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences. Any data that has been collected prior to your withdrawal will be fed back to you if you desire before being deleted and removed from any future analysis.

Will anyone else know the results of the project?

All the information collected will be confidential and known only to the researchers. The findings of this study will not influence your selection within the team. The results of the study will be written up for publication, however, in no way will your results be identifiable to you.

Will I be able to find out the results of the project?

You will be able to find out your individual data, and the averages for the group. This information will be emailed to you individually.

Who do I contact if I have questions about the project?

Should you have any questions regarding this project, please use the following contacts:

Principal Investigator:
Dr. Tim Gabbett
07 3623 7589
tim.gabbett@acu.edu.au

Student Researcher:
Rich Johnston
07 3623 7726
richard.johnston@acu.edu.au

School of Exercise Science, Australian Catholic University, 1100 Nudgee Road, Banyo, QLD, 4014

What if I have a complaint or any concerns?

The study has been reviewed by the Human Research Ethics Committee at Australian Catholic University (review number 2014 XXX). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Manager, Ethics
c/o Office of the Deputy Vice Chancellor (Research)
Australian Catholic University
North Sydney Campus
PO Box 968
NORTH SYDNEY, NSW 2059
Ph.: 02 9739 2519
Fax: 02 9739 2870
Email: resethics.manager@acu.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

I want to participate! How do I sign up?
Please inform Rich Johnston in person or via email or phone and complete the informed consent form.

Yours sincerely,

Dr Tim Gabbett
Principal Investigator

Rich Johnston
Student Investigator

Consent Form

TITLE OF PROJECT: The influence of training on fitness and the fatigue response to simulated rugby league competition.

PRINCIPAL INVESTIGATOR: Dr. Tim Gabbett

STUDENT RESEARCHER: Rich Johnston

PROGRAM IN WHICH ENROLLED: Doctor of Philosophy

I .... *(the participant)* have read (*or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves assessing physical fitness and fatigue, comprised of a countermovement jump and a questionnaire, following a small-sided training game. I am aware that I will be required to wear a GPS unit during the small-sided game that will be recorded by a video camera for assessing skill involvements.

Realising that I can withdraw my consent at any time, without comment or penalty or affect upon my future relationship with the researchers or the team, I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT:...

SIGNATURE: ....DATE:...................................

For office use only:

NAME OF PRINCIPAL INVESTIGATOR: ....

SIGNATURE: ....DATE:……………….........

Ethics Approval

Each study within this thesis received ethical approval from Australian Catholic University Human Research Ethics Committee prior to any data being collected. Evidence of approval from the ethics committee is outlined below from Australian Catholic University's online ethics application programme.

Studies 1-3 Approval ID: 2013 315Q

From: **Res Ethics** Res.Ethics@acu.edu.au
Subject: 2013 315Q Ethics application approved!
Date: 1 April 2014 14:47
To: Tim Gabbett Tim.Gabbett@acu.edu.au, Richard Johnston Richard.Johnston@acu.edu.au
Cc: Res Ethics Res.Ethics@acu.edu.au

RE

Dear Applicant,

Principal Investigator: Dr Timothy Gabbett
Student Researcher: Mr Richard Johnston (HDR student)
Ethics Register Number: 2013 315Q
Project Title: Influence of the number of contact efforts on subsequent running performance during game-based training activities
Risk Level: Low Risk 2
Date Approved: 01/04/2014
Ethics Clearance End Date: 30/06/2014

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

This project has been awarded ethical clearance until 30/06/2014. In order to comply with the National Statement on Ethical Conduct in Human Research, progress reports are to be submitted on an annual basis. If an extension of time is required researchers must submit a progress report.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. The Chief Investigator is responsible for ensuring that appropriate permission letters are obtained, if relevant, and a copy forwarded to ACU HREC before any data collection can occur at the specified organisation. Failure to provide permission letters to ACU HREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will only be contacted again in relation to this matter if the Committee raises any additional questions or concerns.

Researchers who fail to submit an appropriate progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress /
Final Report form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

For modifications to your project, please complete and submit a Modification form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,
Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Crittenden

Ethics Officer I Research Services
Office of the Deputy Vice Chancellor (Research)
Australian Catholic University

THIS IS AN AUTOMATICALLY GENERATED RESEARCHMASTER EMAIL

Studies 4 and 8 Approval ID: 2014 05Q

From: **Res Ethics** Res.Ethics@acu.edu.au
Subject: 2014 05Q Ethics application approved!
Date: 11 April 2014 10:34
To: Tim Gabbett Tim.Gabbett@acu.edu.au, Richard Johnston Richard.Johnston@acu.edu.au
Cc: Res Ethics Res.Ethics@acu.edu.au

RE

Dear Applicant,

Principal Investigator: Dr Timothy Gabbett
Student Researcher: Mr Richard Johnston
Ethics Register Number: 2014 05Q
Project Title: The influence of playing standard on fatigue and match performance during an intensified rugby league competition
Risk Level: Low Risk 3
Date Approved: 11/04/2014
Ethics Clearance End Date: 04/07/2014

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research subject to the following conditions:

INSERT CONDITIONS IF APPLICABLE OR N/A

This project has been awarded ethical clearance until 04/07/2014. In order to comply with the National Statement on Ethical Conduct in Human Research, progress reports are to be submitted on an annual basis. If an extension of time is required researchers must submit a progress report.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. The Chief Investigator is responsible for ensuring that appropriate permission letters are obtained, if relevant, and a copy forwarded to ACU HREC before any data collection can occur at the specified organisation. Failure to provide permission letters to ACU HREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will only be contacted again in relation to this matter if the Committee raises any additional questions or concerns.

Researchers who fail to submit an appropriate progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress / Final Report form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

For modifications to your project, please complete and submit a Modification form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,
Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Crittenden

Ethics Officer I Research Services
Office of the Deputy Vice Chancellor (Research)
Australian Catholic University

THIS IS AN AUTOMATICALLY GENERATED RESEARCHMASTER EMAIL

Study 5 Approval ID: 2012 159Q

From: **Tim Gabbett** Tim.Gabbett@acu.edu.au
Subject: FW: Ethics application approved! 2012 159Q
Date: 15 June 2012 16:12
To: Richard Johnston Richard.Johnston@acu.edu.au

TG

From: Kylie Pashley On Behalf Of Res Ethics
Sent: Friday, 15 June 2012 4:08 PM
To: Tim Gabbett; Richard Johnston
Subject: Ethics application approved! 2012 159Q

Dear Tim and Richard,

Principal Investigator: Mr Tim Gabbett
Student Researcher: Mr Richard Johnston
Ethics Register Number: 2012 159Q
Project Title: Influence of fatigue on match performance in junior rugby league players during an intensified competition
Risk Level: Low Risk
Ethics Clearance End Date: 15 July 2012

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance or permissions from other organisations to access staff. Therefore the proposed data collection should not commence until you have satisfied these requirements.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will only be contacted again in relation to this matter if the Committee raises any additional questions or concerns.

This project has been awarded ethical clearance until 15 July 2012 and a progress report must be submitted at least once every twelve months.

Researchers who fail to submit an appropriate progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress / Final Report form:
http://www.acu.edu.au/about_acu/research/staff/research_ethics/

For modifications to your project, please complete and submit a Modification form:
http://www.acu.edu.au/about_acu/research/staff/research_ethics/

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,
Insert REO name

Ethics Officer I Research Services
Office of the Deputy Vice Chancellor (Research)
Australian Catholic University

THIS IS AN AUTOMATICALLY GENERATED RESEARCHMASTER EMAIL

Studies 6 and 7 Approval ID: 2012 264Q

Dear Tim and Richard,

Principal Investigator: Dr Timothy James Gabbett
Student Researcher: Richard Johnston
Ethics Register Number: 2012 264Q
Project Title: The influence of fitness on the fatigue response to simulated rugby league competition
Risk Level: Low Risk
Date Approved: 13/12/2012
Ethics Clearance End Date: 30/06/2013

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

This project has been awarded ethical clearance until 30/06/2013. In order to comply with the National Statment on Ethical Conduct in Human Research, progress reports are to be submitted on an annual basis. If an extension of time is required researchers must submit a progress report.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance or permissions from other organisations to access staff. Therefore the proposed data collection should not commence until you have satisfied these requirements.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will only be contacted again in relation to this matter if the Committee raises any additional questions or concerns.

Researchers who fail to submit an appropriate progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress / Final Report form:
http://www.acu.edu.au/about_acu/research/staff/research_ethics/

For modifications to your project, please complete and submit a Modification form:
http://www.acu.edu.au/about_acu/research/staff/research_ethics/

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,
Gabrielle Ryan

Ethics Officer I Research Services
Office of the Deputy Vice Chancellor (Research) Australian Catholic University

THIS IS AN AUTOMATICALLY GENERATED RESEARCHMASTER EMAIL

Study 9 Approval ID: 2014 291Q

From: **Res Ethics** Res.Ethics@acu.edu.au
Subject: 2014 291Q Ethics application approved!
Date: 9 January 2015 15:25
To: Tim Gabbett Tim.Gabbett@acu.edu.au, Richard Johnston Richard.Johnston@acu.edu.au
Cc: Res Ethics Res.Ethics@acu.edu.au

RE

Dear Applicant,

Principal Investigator: Dr Timothy Gabbett
Student Researcher: Richard Johnston (Research student)
Ethics Register Number: 2014 291Q
Project Title: The influence of training on fitness and the fatigue response to simulated rugby league competition
Risk Level: Low Risk
Date Approved: 09/01/2015
Ethics Clearance End Date: 30/06/2015

This email is to advise that your application has been reviewed by the Australian Catholic University's Human Research Ethics Committee and confirmed as meeting the requirements of the National Statement on Ethical Conduct in Human Research.

This project has been awarded ethical clearance until 30/06/2015. In order to comply with the National Statement on Ethical Conduct in Human Research, progress reports are to be submitted on an annual basis. If an extension of time is required researchers must submit a progress report.

Whilst the data collection of your project has received ethical clearance, the decision and authority to commence may be dependent on factors beyond the remit of the ethics review process. The Chief Investigator is responsible for ensuring that appropriate permission letters are obtained, if relevant, and a copy forwarded to ACU HREC before any data collection can occur at the specified organisation. Failure to provide permission letters to ACU HREC before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research. Further, this approval is only valid as long as approved procedures are followed.

If you require a formal approval certificate, please respond via reply email and one will be issued.

Decisions related to low risk ethical review are subject to ratification at the next available Committee meeting. You will be contacted should the Committee raises any additional questions or concerns.

Researchers who fail to submit a progress report may have their ethical clearance revoked and/or the ethical clearances of other projects suspended. When your project has been completed please complete and submit a progress/final report form and advise us by email at your earliest convenience. The information researchers provide on the security of records, compliance with approval consent procedures and documentation and responses to special conditions is reported to the NHMRC on an annual basis. In accordance with NHMRC the ACU HREC may undertake annual audits of any projects considered to be of more than low risk.

It is the Principal Investigators / Supervisors responsibility to ensure that:
1. All serious and unexpected adverse events should be reported to the HREC with 72 hours.
2. Any changes to the protocol must be approved by the HREC by submitting a Modification Form prior to the research commencing or continuing.
3. All research participants are to be provided with a Participant Information Letter and consent form, unless otherwise agreed by the Committee.

For progress and/or final reports, please complete and submit a Progress / Final Report form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

For modifications to your project, please complete and submit a Modification form:
http://www.acu.edu.au/research/support_for_researchers/human_ethics/forms

Researchers must immediately report to HREC any matter that might affect the ethical acceptability of the protocol eg: changes to protocols or unforeseen circumstances or adverse effects on participants.

Please do not hesitate to contact the office if you have any queries.

Kind regards,
Kylie Pashley
on behalf of ACU HREC Chair, Dr Nadia Crittenden

Ethics Officer I Research Services
Office of the Deputy Vice Chancellor (Research)
Australian Catholic University

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